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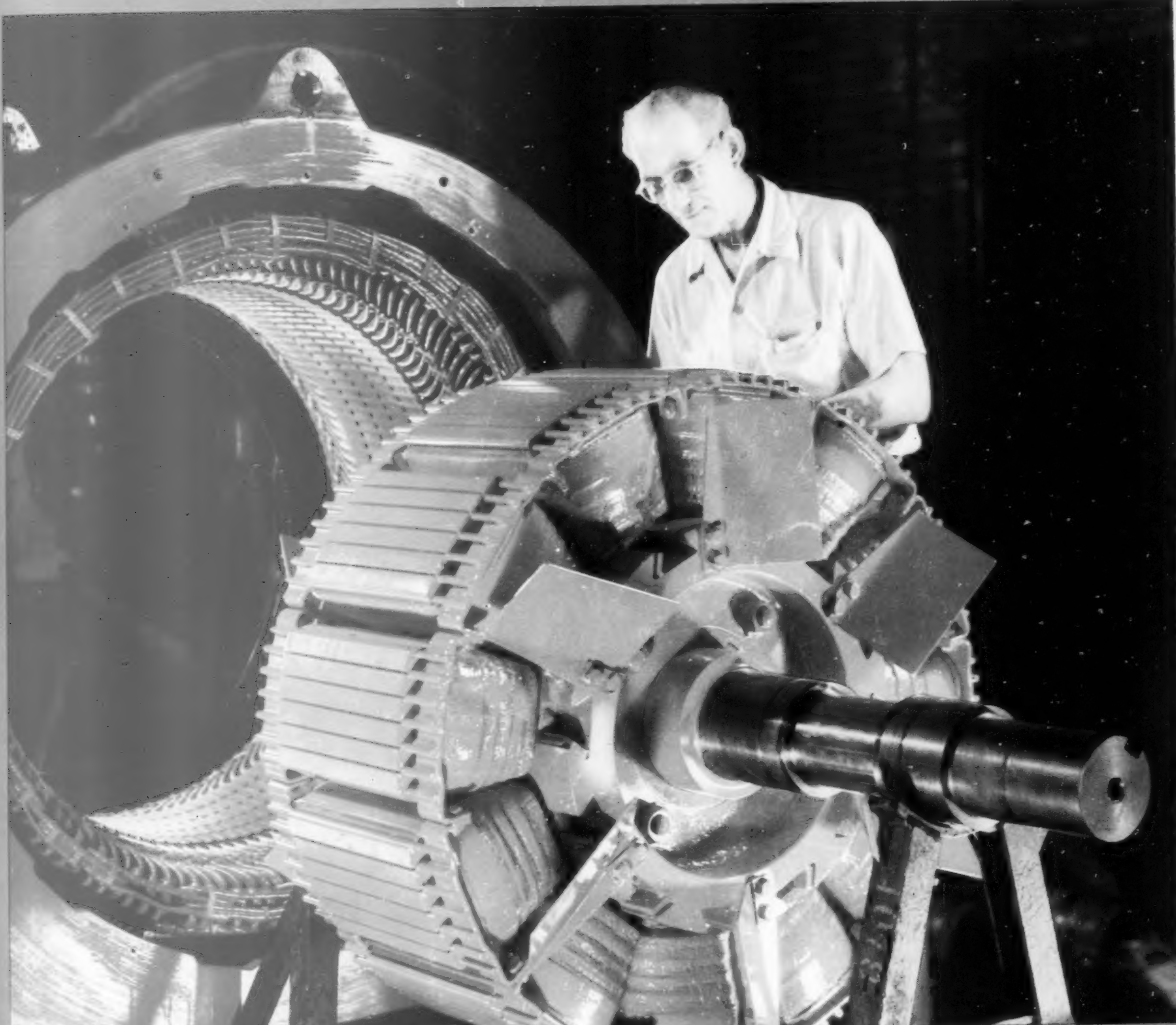
ALLIS-CHALMERS Electrical REVIEW

3RD QUARTER 1956



NEW INSULATION SEALS IN PERMANENT DYNAMIC STRENGTH... PAGE 4

ALLIS-CHALMERS Electrical REVIEW

THE COVER

CONSTANT RESEARCH, EVALUATION and development of new materials have pointed the way. Now the result — two outstanding insulation developments teamed to simplify maintenance procedures and extend life expectancy of synchronous motors! *Silco-Flex* stator coil insulation and "Integrated" rotor coils are impervious to penetration by even the most pernicious contaminants this 600-hp, 2300-volt, 600-rpm rubber mill drive motor will encounter.

Color Cover and Center Spread are A-C Staff Photos by M. Durante

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"INTEGRATED" ROTOR COILS— Bonded to Extend Salient-Pole Motor Life


by J. L. KUEHLTHAU
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Insulation Design

and J. W. SARGENT
Motor and Generator Dept.
Allis-Chalmers Mfg. Co.

This new development holds promise of reduced maintenance and longer life for synchronous motors.

A NEW, MORE DURABLE and physically stronger rotor coil structure has recently been developed. An "Integrated" structure with conductors, insulation, and pole piece bonded into one complete unit, this development will mean longer life and reduced maintenance for synchronous motors and other salient-pole machines.

Impervious to dust, dirt, and oil, "Integrated" rotor coils will assure more dependable motor operation, especially where duty cycles are severe and ambient air is contaminated. Designed to provide waterproofness and chemical resistance, this new "Integrated" rotor coil structure has mechanical strength comparable to steel. These same characteristics hold significant promise that enclosure requirements can be reduced for machines employing this development.

Conventional coil structures, while basically satisfactory for most applications, have failed when exposed to unusually severe operating conditions. Coil loosening, coil and material shrinkage, and electrical failures caused by fatigue have all been maintenance considerations and factors contributing to the eventual structural failure of conventional coils.

"Integrated" rotor coil construction is expected to virtually eliminate these problems. Synchronous motors and generators featuring this development, complemented by *Silco-Flex* insulated stator coils,* are especially well suited for the applications and ambient conditions associated with rubber, plastic, and chemical processing plants.

CROSS SECTION through "Integrated" rotor coil and pole piece shows insulating bond between conductors, the bonding of coil structure to the pole piece, and the homogeneity of the entire coil structure. **(FIGURE 1)**

For example, in plants processing rubber and some plastic materials, an essential element, carbon black, has been an especially pernicious foe of electrical insulations. Conventional insulating systems have not kept minute carbon particles from penetrating the coil structure and lowering dielectric strength.

In the metals industries, conductive dust particles are frequently present in the atmosphere, and under unusual service conditions have caused coil failure in much the same manner as experienced with carbon black. In contrast, the smooth, continuous and void-free exterior surface of the "Integrated" coil—bonded even to the pole piece—eliminates all points of collection and entry for harmful particles, as indicated by Figures 1 and 2.

Although developed primarily to overcome weaknesses found in earlier rotating field coil construction, the "Integrated" coil structure is equally adaptable to stationary field coils of direct current motors and generators.

Mechanical properties paramount

While this development is primarily an insulation system with excellent dielectric strength, mechanical properties are perhaps even more important. Compression caused by centrifugal force . . . expansion and contraction resulting from thermal cycling . . . fatigue at elevated tempera-

* "*Silco-Flex* Insulation . . . Opening the Way to Longer Motor Life," J. L. Kuehlthau and P. A. Kryder, Allis-Chalmers *Electrical Review*, Second Quarter, 1955.

TABLE I

Material	Ultimate Strength, P.S.I.	
	Tension	Compression
Structural Steel	60,000	60,000
Wrought Iron	48,000	48,000
Integrated Coil Covering	42,800	48,300
Granite	700	19,000
Bricks (Best Hard)	400	12,000
Concrete (Portland)	200	1,000

WHEN COMPARED to structural materials, the "Integrated" coil covering approaches iron and steel in tension and compression strengths, is superior to most non-ferrous materials.

BONDED at the coil lead (1) and to the pole piece (2), "Integrated" construction seals out ambient contaminants. Copper and insulation (3) have the same coefficient of lineal expansion. **(FIGURE 2)**

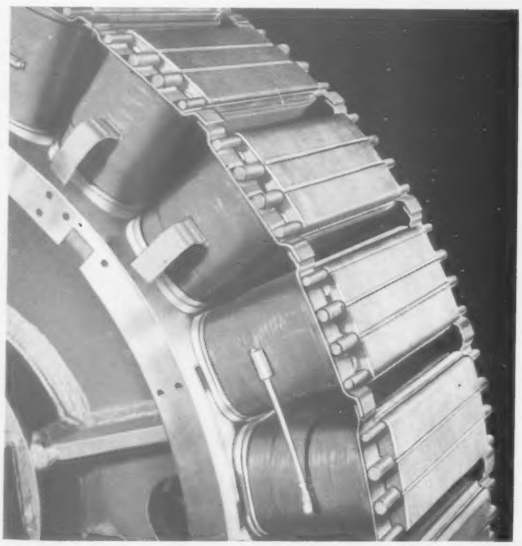
tures . . . and vibration — all tend to degrade rotating salient-pole coil structures. Dielectric weaknesses are almost invariably the result of mechanical degradation from one or more of these causes plus infiltration of contaminants.

To achieve the high degree of mechanical strength necessary for extended coil life, a fiber glass reinforced resin laminate was selected as the material for this insulating system. Its tensile and compressive strengths are compared in Table I to common structural materials. In Table II its tensile, flexural, compressive, and impact strengths are compared with four other laminated insulating materials.

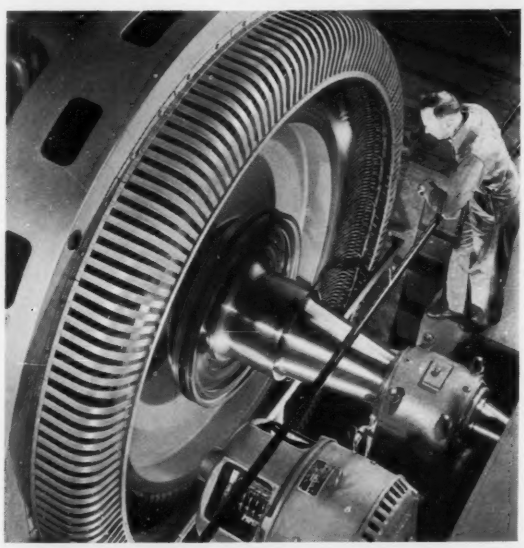
Glass fiber constitutes more than 60 percent of the material used in this system. Long, cross-plied glass filaments are tailored in length and oriented in direction to achieve maximum strength. This construction makes possible a glass laminate with exceptionally high strength. A practically indestructible coil structure results. Rotor-mounted coils are shown in Figure 3.

Consistent with this construction, the magnet wire fiber glass insulation used in "Integrated" field coils was developed for improved bondability. Ordinary glass-insulated wire proved less satisfactory because its smooth finish does not permit a bond consistent in strength with the rest of the structure.

Unlike commonly termed "encapsulated" field coils in which varnishes, resins, or wrappers of various types have



HIGH COMPRESSIVE STRENGTH and other mechanical properties make the "Integrated" coil structure extremely resistant to degradation from both compression and thermal cycling. **(FIGURE 3)**



SYNCHRONOUS MOTORS combining "Integrated" rotor coils and *Silco-Flex* stator coil insulation promise simplified maintenance procedures — especially in applications where duty is severe. **(FIGURE 4)**

TABLE II

Rockwell Hardness	Physical Strengths Measured in PSI			*Impact Strength Ft/Lb per Inch of Notch
	Tensile	Flexural	Compressive	
105-110	8,000-12,000	14,000-19,000	36,000-40,000	1.3- 3.2
110	8,000-11,000	11,000-17,000	17,000-40,000	.6- 1.9
100	5,000-10,000	15,000-25,000	46,000	10.0-15.0
120	30,000-37,000	35,000-48,000	25,000-70,000	5.5- 2.7
100-110	42,800	55,000-65,000	48,300	21.0-37.0

* IZOD Test Procedure

COMPARED WITH FOUR other laminated insulating materials, the "Integrated" coil covering material was measurably superior.

TABLE III

Material	Water Absorption (Percent in 24 Hours)
Canvas Fabric Phenolic	.75-2.2
Asbestos Paper Phenolic	.55-1.5
Glass Mat Polyester	.2 - .7
Glass Fabric Melamine	1.2 -2.7
"Integrated" Coil Covering	.04- .1

WHEN IMMERSED in water, the "Integrated" coil covering material proved superior to the same four materials in resisting absorption.

been used to provide a protective sheathing around an otherwise conventionally constructed coil, this development provides much more than a sheath-like covering. Materials used throughout this system were selected because of their ability to bond together and to the copper conductors. Insulating materials and copper conductors are pressure molded into one complete and "Integrated" structure. The smooth finish of the coil exterior, clearly visible in the cover picture, results from this pressure molding. Completed coils are in turn bonded, sealed, and locked to the pole pieces.

In determining what combination of materials would give the best results, each component was tested individually as well as in a finished coil structure. Some substances gave excellent results when tested separately but proved unsatisfactory in combination with others. For example, certain materials inhibited others in the curing process and were consequently rejected.

Superior thermal characteristics

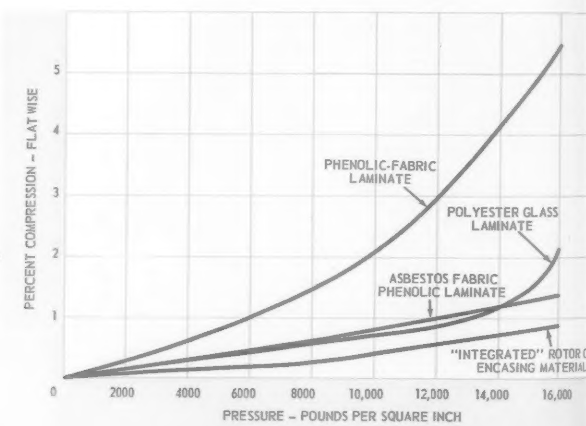
Mechanical strength and dimensional stability, essential to withstand the compression of centrifugal force, were not the only requirements complicating material selection.

Since the insulating material of the "Integrated" coil structure performs the additional functions of surrounding and bonding the copper conductors, an imperative requirement was that it have a coefficient of lineal expansion as near identical to that of copper as possible.

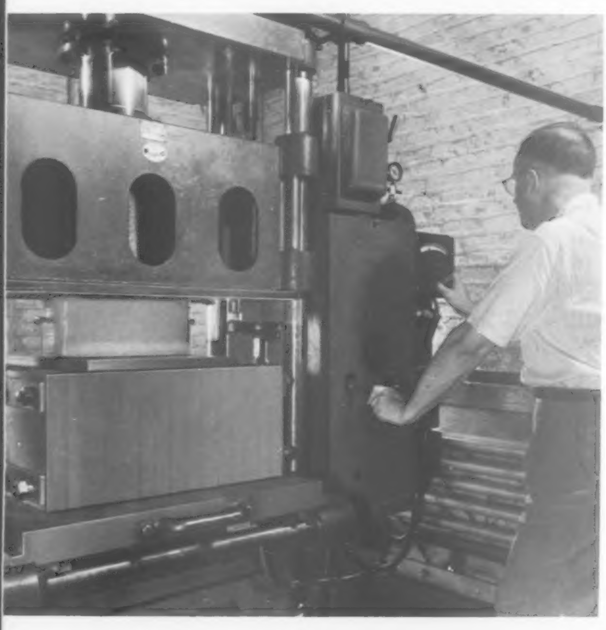
The coefficient of expansion for copper is .00000887; for the insulating material used in the "Integrated" coil, .0000088.† This characteristic enables the "Integrated" coil structure to withstand the rigors of the most severe thermal cycling.

The "Integrated" coil structure is also bonded to the pole piece. However, because of the differential between

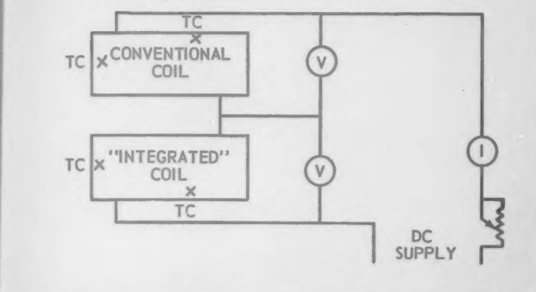
† Coefficient of expansion per unit length per degree F.



AT CONSTANTLY elevated temperatures, simulating operating conditions, the "Integrated" coil encasing material showed superior resistance to compression. **(FIGURE 5)**



A COMPLETED coil structure, less pole piece, is subjected to high pressures in a hydraulic press by one of the authors. **(FIGURE 6)**

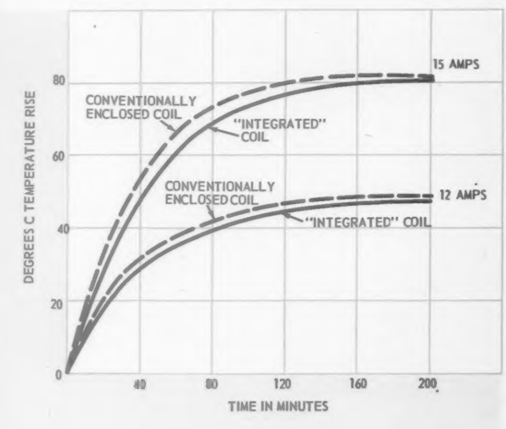


THIS SCHEMATIC shows the placement of thermocouples and the circuit used to energize coils during heat dissipation tests. **(FIGURE 7)**

coefficients of expansion for steel and for the copper insulating material structure, a specially designed mechanical locking device is also employed to further assure the rigidity of the entire pole piece assembly. Since the coil structure expands more rapidly than the pole piece, only the somewhat resilient bond between insulation material and pole piece ends is stressed.

Even at the constantly elevated temperatures employed in accelerated life tests, compression strength of the glass-reinforced insulating material is high. Its substantial superiority to comparable materials at high pressure and elevated temperature is indicated by the curves of Figure 5. Figure 6 shows a completed form-wound coil under pressure in a hydraulic press.

Results from tests conducted to determine heat dissipation characteristics of the "Integrated" coil design as compared to conventionally enclosed coils are shown in Figure 8. In these tests, air was blown over the wire-wound



HEAT DISSIPATION test results indicated that machines equipped with "Integrated" coils will operate as cool as those having conventionally enclosed coils. **(FIG. 8)**

coils at a velocity of 165 feet per minute, approximately equal to the air velocity of a 500-hp, slow speed synchronous motor. Results show that "Integrated" coils operate at least as cool as coils of conventionally enclosed design.

The unit construction of the "Integrated" field coil insulation system is used for both form-wound and pole-wound coils. Form-wound coils are processed complete, off the pole, and are then cast in place on the pole.

Pole-wound "Integrated" coils are made to hug the pole laminations and are bonded directly to the pole steel by the resin-filled glass fibers surrounding the coil body. Because of this bond, both types (pole and form wound) dissipate heat at approximately the same rate as conventional encased coils.

Bonded dielectric structure is voidless

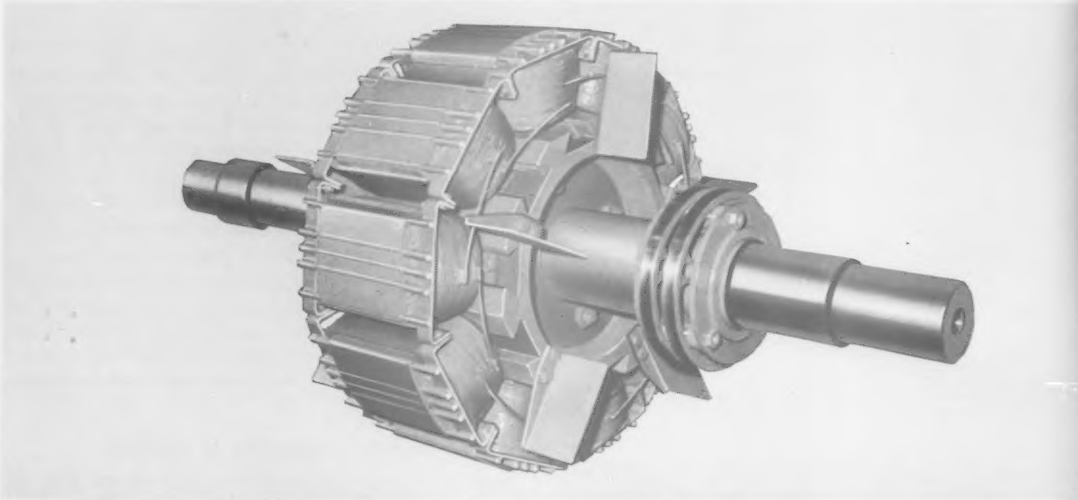
In the "Integrated" coil structure, all voids are filled by bonding resins which are selected for their resiliency, bond strength and dimensional stability. Dielectric strength of the resin-reinforced glass laminate exceeds 400 volts per mill at 23 C. All resins are of the same family, are fully compatible, and possess heat stable properties. The resins are 100 percent solids and react with heat and pressure so that there is no solvent porosity or entrapment. This voidless structure assures a permanent seal against all contaminants and provides optimum conditions for maximum thermal conductivity.

A vulnerable spot in coil insulating systems has been the point at which connecting leads make their exit from the coil body. It is here that dirt and contaminants have entered to cause shorting of turns. In the "Integrated" field coil system, each lead is completely isolated from the rest of the coil from its point of origin to the place where it is brought out through the coil wall, thus completely sealing all entries for contaminants. The ease with which dirt can be removed from the coil structure is demonstrated in Figure 9.

Chemical properties are superior

Of particular importance when considering motor applications for humid or contaminated atmospheres is the ability of insulating materials to resist moisture and corrosive vapors. Since even explosion-proof enclosures do not seal out ambient atmosphere, the resistance of insulation materials to corrosive or contaminating elements is an important consideration.

EASY REMOVAL of dirt and contaminants from the hard, nonporous coil surface is demonstrated. **(FIGURE 9)**



TYPICAL of relatively high speed salient-pole synchronous motor rotors, this 720-rpm, 10-pole rotor is equipped with "Integrated" coils. **(FIGURE 10)**

When subjected to immersion tests in water, oil, alkalies, and acids, reinforced glass fiber insulating material used for the "Integrated" rotor coil structure showed excellent stability. Its low rate of water absorption is compared to that of four other materials in Table III.

In addition to its resistance to contaminants, this material is thermally stable, fungus resistant, non-corrosive, and flame retardant.

Motors with "Integrated" coils now available

Salient-pole synchronous motors and generators employing "Integrated" rotor coil structures are now in production. This premium insulating system for severe service conditions is also available for the field structures of dc machines. Presently suitable for Class A and B temperature rises, it is anticipated that in the near future resin improvements and developments currently in progress will enable the production of coils for Class H temperatures.

The "Integrated" coil was conceived to eliminate shortcomings of conventional field coils and to assure longer motor life in special applications. This development is expected to eliminate numerous maintenance factors of present salient-pole machines.

Experience to date indicates that synchronous machines combining *Silco-Flex* insulated stator coils with "Integrated" rotor coils will last longer while requiring less care and maintenance than rotating machines employing any other insulating systems presently available.

"INTEGRATED" construction excludes contaminants from coil conductors in this 500-hp, rubber mill drive motor rotor. **(FIGURE 11)**

"INTEGRATED" coil design is also adaptable to salient-pole direct current field coils. **(FIGURE 12)**

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STUDY IN SYMMETRY — the reaction blades in one-half the inner high pressure cylinder for a 300,000-kilowatt, close-coupled cross-compound steam turbine-generator unit are being inspected. At maximum load, the reaction section of this high pressure turbine will deliver over 100,000 horsepower to the coupling of the turbine-generator.

New Developments and High Product Quality Accent the Men Behind the Equipment and . . .

The Guided Self-Development of Engineers

by **PAUL NIPPES**
Motor and Generator Dept.

and

WILLIAM MARGOPOULOS
Office of Director of Engineering
Allis-Chalmers Mfg. Co.

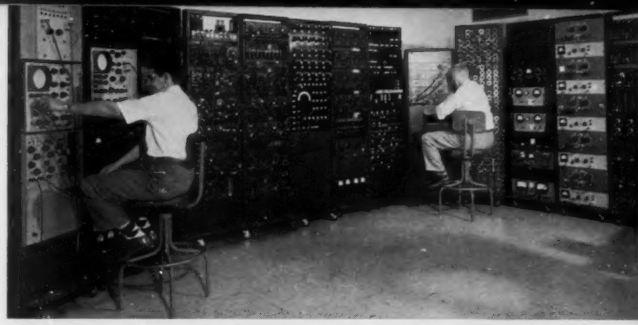
TODAY'S SHORTAGE of engineering talent—in an economy of constantly increasing demands for products based largely on engineering developments—has focused considerable attention on programs to utilize qualified engineering personnel more effectively. Also in the spotlight are programs that not only train young graduate engineers, but help them find the particular function in industry for which they are best suited.

Equipped by his undergraduate school with an appreciation for the breadth of engineering, the new engineer frequently enters industry without any precise knowledge of how his learning can be applied to greatest advantage for himself and society. He is generally aware that knotty problems in one branch of engineering are often solved by borrowing technology from another. Knowing this, he may be reticent to limit future training to the relatively narrow areas usually associated with engineering specialization.

While most large manufacturers have some type of graduate training program to guide the transition from school to industry, very few of these programs are based on the fundamental concept that only by maintaining a broad understanding of engineering advances can engineers expect to benefit from accomplishments in other fields.

Developing engineers to develop products

Cognizance of the need for coordination among engineers of varying specialties resulted in the establishment, some



50 years ago, of a two-year graduate training program at Allis-Chalmers. Under this program, arranged in a manner that assures the young engineer of training in many locations of his choice, the trainee has ample and diversified opportunity to broaden himself while finding his particular place in industry. On the other hand, should he enter industry knowing the type of work he wants, his activities can be concentrated toward his specific objective. In any case, he works for and with company engineers on engineering problems in a variety of engineering fields.

To help the engineering graduate find his place in industry, and to augment his academic training, seven courses are offered on a part-time basis within the graduate training program. These include: an electrical lecture course; a business fundamentals course for engineers; a sales training course; the Engineering Technical Course; and various product department courses such as processing machinery, steam turbine, hydraulic turbine, switchgear, nuclear power, and transformer.

Of these various courses, the Engineering Technical Course perhaps best exemplifies the underlying philosophy of engineering training within the company. A typical curriculum of this course is given in Figure 1. Specifically, its purpose is to prepare the young engineer with creative and analytical aptitudes for early and continued accomplishments and advancements in development and design engineering.

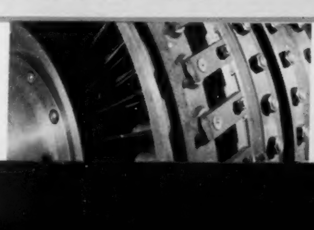
Any graduate who is interested in taking the Engineering Technical Course is encouraged to make application. Each group is limited to no more than 15 members. This is done to stimulate an informal atmosphere and to encourage participation by every member. Members are chosen on the basis of past accomplishments, sincere interest in the course, and freedom from conflict with per-

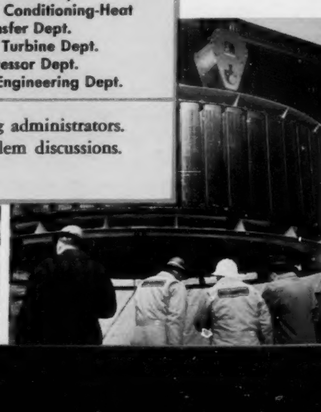
ENGINEERING TECHNICAL COURSE TYPICAL CURRICULUM (FIGURE 1)

SESSION	8:15 - 9:15 A.M. PROBLEM PRESENTED BY:	9:20 - 11:25 A.M. ENGINEERING FUNDAMENTALS LECTURES	11:25 - 12:30 P.M. PROBLEMS DISCUSSED
1*			
2	Plant Engineering Dept.	Electrical-Mechanical Analogies	† (See note)
3	Electrical Application Dept.	Effective Reading	† (See note)
4	Compressor Department	Engineering Analysis	Plant Engineering Dept.
5	Switchgear Department	Engineering Analysis	Electrical Application Dept.
6	Transformer Department	Vibrations — I	Compressor Dept.
7	Hydraulic Turbine Dept.	Vibrations — II	Switchgear Dept.
8	Centrifugal Pump Dept.	Laplace Transforms	Transformer Dept.
9	Processing Machinery Dept.	Dimensional Analysis	Hydraulic Turbine Dept.
10	Motor & Generator Dept.	Creative Session	Centrifugal Pump Dept.
11	Norwood Development Laboratory	Feedback Control Circuits — I	Processing Machinery Dept.
12	Control Department	Feedback Control Circuits — II	Motor & Generator Dept.
13	Nuclear Power Department	Fluid Flow	Norwood Development Lab.
14	Analytical Group	Stress Analysis	Control Department
15	Water Conditioning-Heat Transfer Department	Heat Transfer	Nuclear Power Dept.
16	Steam Turbine Dept.	Creative Session	Analytical Group
17	Compressor Dept.	Engineering Analysis	Water Conditioning-Heat Transfer Dept.
18	Plant Engineering Dept.	Analogies	Steam Turbine Dept.
19	††Analogies	Patent Department	Compressor Dept.
20	††Computing Laboratory	Research Laboratories	Plant Engineering Dept.

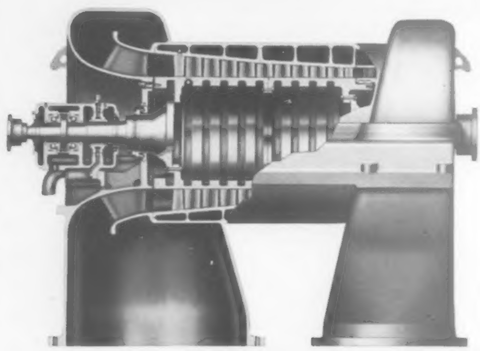
* In the first session, course objectives are explained by Director of Engineering and other engineering administrators.
† For the first two weeks of the course, creative sessions are held in the period later devoted to problem discussions.
†† The last two periods normally devoted to problem presentation are devoted to lectures.

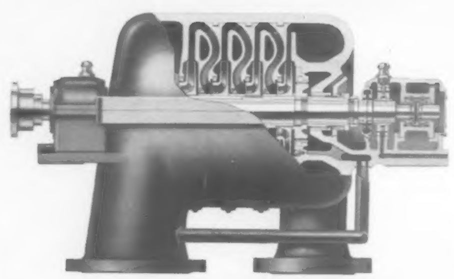
PICTURED from top to bottom, left to right, are: computer laboratory, cement plant model, condenser for nuclear power plant turbine, insulation development group, nuclear power plant model, 600-kv power transformer, axial compressor rotor, and world's largest reversible generator/motor rotor.





IN A PETROLEUM PRODUCING PLANT, three compressors are to operate in series. They have been designed to handle a gas with a molecular weight of 34 and a K value of 1.12. Due to the explosive nature of the gas, it is necessary to start these units on nitrogen with a molecular weight of 28 and a K value of 1.40. Give detailed instructions and equipment required for bringing this system of three compressors up to speed on nitrogen and then transferring to the process gas without exceeding the safe operating limits of the compressors. **(FIGURE 2)**





Note: Figures 2 thru 9 are problem synopses only. When presented in the course, all required information was given. Figure 10 exemplifies a complete presentation.

sonal schedules, since each participant must spend a considerable amount of his personal time solving engineering problems. A desire to do more than is required on a specific task plus an ambition for self-improvement are the distinguishing characteristics that result in a better engineer — and ultimately better engineered, more reliable products.

Course encourages initiative

Half-day weekly meetings consist of problem presentations and discussions along with lectures and creative sessions. The course is designed to encourage individual initiative. Each member can pursue his studies completely unfettered by do's, don'ts, and conventional approaches.

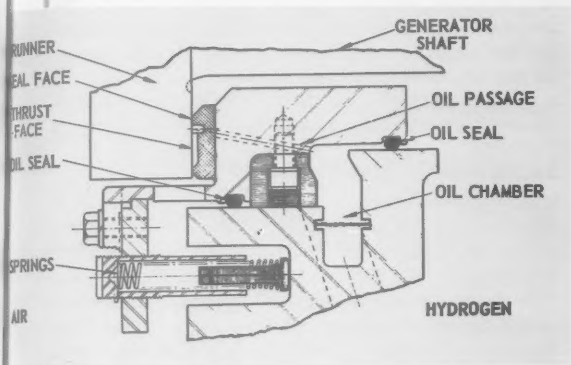
The full program covers a period of five months and requires that each student devote a considerable amount of his personal time to homework. Because of this, classes are scheduled to coincide with college semesters so that students pursuing graduate studies at local universities need defer their academic training only one semester. This course is designed to complement graduate study by helping the student to increase not only his knowledge, but also his perspective in the field of engineering.

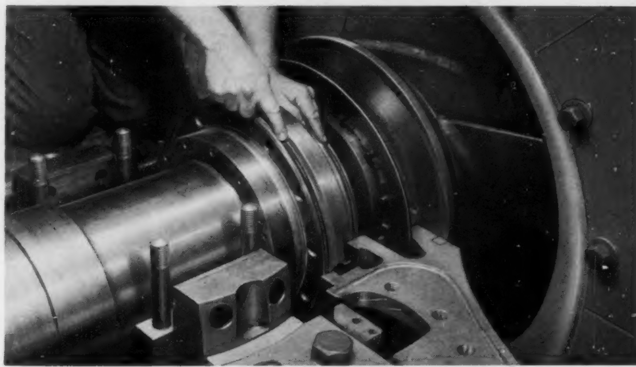
In making up a class, there is no division between electrical, mechanical, or other types of graduate engineers. This has a broadening effect. Each gains the opportunity to advance in his own field while becoming better acquainted in other fields of engineering. This broad base gives the young engineer a reference point to help determine the degree of specialization he may want to assume when selecting his professional field.

Scope and general planning are formulated by the Director of Engineering, local educators, and consulting engineers. Specific problems and lectures are selected on the advice of chief engineers. Each class has an entirely new and original program which is arranged by a class coordinator. He works through the Office of Director of Engineering on technical matters and in cooperation with the Graduate Training Department. The latter serves the functions of keeping records, performing operational duties, grouping students for the course, and maintaining a balanced overall program.

HERMETICALLY SEALED or canned motor pump design is used to obtain an absolutely leakless unit. It consists essentially of eliminating the normal shaft seal between motor and pump. The fluid being pumped occupies the "air gap" between motor rotor and stator. To contain the fluid and to keep the stator dry, a cylindrical liner (.020 to .060 inch thick) is placed in the bore of the stator and welded to the end heads of the stator housing. The housing is bolted directly to the pump casing to complete the confinement of the fluid. Determine the hot-spot temperature of the motor stator winding. **(FIGURE 3)**

SUGGEST DESIGN MODIFICATIONS or a new design for a supercharged generator hydrogen seal that will meet future pressure requirements which may exceed 90 psig. **(FIGURE 4)**





Engineering fundamentals in action

Lectures programmed for the Engineering Technical Course are given by engineering specialists. An example of this is the lecture on dimensional analysis which is given by the scientist in charge of the Mechanical Laboratory of the Research Division. These specialists are equipped to dramatize engineering fundamentals in action with practical engineering illustrations. Lecture topics include the fundamentals of mechanical and electrical engineering, and advanced mathematics. In addition to the technical lectures there are lectures covering important topics of patent applications and effective reading.

Every effort is made to keep the course truly representative of industry. Problems are usually presented by chief engineers or supervisory engineers of product departments. The wide diversification of company products lends itself ideally to fulfilling the course objectives by supplying many different types of problems.

The greatest benefit of the Engineering Technical Course comes through presentation, resolution, and discussion of problems offered by various departments. Most problems selected, Figures 2 through 10 are examples, are of current interest to the department presenting the problem. In some cases, new and unique approaches are sought. Each problem is intentionally stripped to its basic form so that no method of solution is inferred in the presentation. The nature of problem presentations is indicated by Figures 2 through 10. Complete data are not given in these examples; however, problem diversity is demonstrated. An informal class discussion and suitable references provide the starting point for problem solution. The course coordinator and the engineer presenting the problem are available for consultation at any time during the one week which is allotted for working the problem.

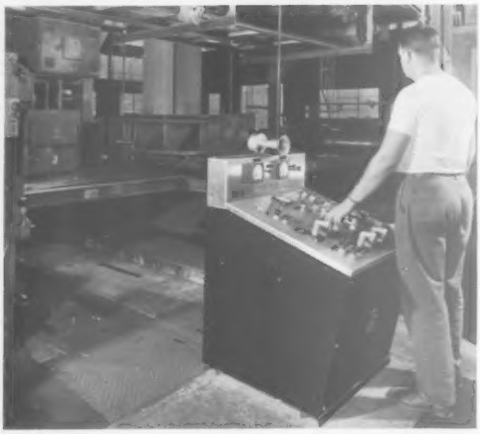
Solutions are collected at the next class session. Each member in rotation collects and classifies the solutions as to approach and results. He then turns them over to the department which presented the problem. Here they are evaluated by engineers of long experience in the particular field who make suitable marginal comments concerning the techniques and basis of solution. During the following class meeting, one hour is allotted for a thorough discussion of the problem, approaches, and solutions. Discussion is guided by the engineer who originally presented the problem. Solutions are then turned over to the class coordinator who reviews them before returning them to the students.

Generally, the several different approaches used in solving problems can be placed in one of three general categories. First, those which are in line with, or similar to, the departmental method. Second, those which are workable but not too practical. Third, those which present new or different techniques and are deserving of further consideration. A member with a solution in the latter class may be asked to work further along the lines of his approach to evaluate its true worth. He may choose to take a regular Graduate Training Course assignment in the department concerned and carry out this project to his and the department's satisfaction.

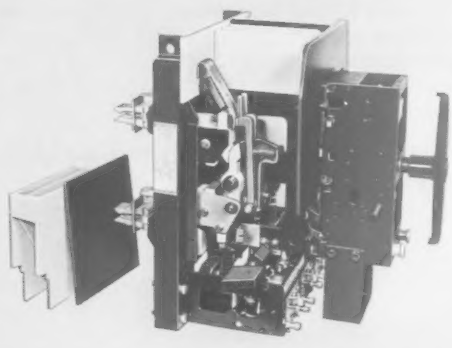
Students gain both technology and confidence

Lectures and problems for the Engineering Technical Course are not given in the formal classroom manner. Their primary importance is to inform and stimulate. Increased technology is gained through self-study and is a function of the student's own initiative. Deriving solutions to the problems that are presented usually requires a good deal of library research. It is through this means that the member of the ETC becomes more adept at applying familiar and unfamiliar physical laws and theorems.

Students frequently become highly interested in problems requiring research and understanding for which college training is merely a stepping stone. For example, the derivation of a formula for transformer leakage reactance for a shell-type transformer interested one student to the extent that he used an analog model attack. Using a conducting paper and electrodes, he established the electro-



REGULATION OF SPEED is of utmost importance for a uniform product in a continuous process line for which equipment is being specified. Determine if the system is stable and, if necessary, what damping is required. **(FIGURE 5)**



SUGGEST A DESIGN for non-bouncing contacts for use in circuit breakers. **(FIGURE 6)**

static fields, and hence the orthogonal magnetic field lines, thereby determining the leakage.

On other problems, as on this one, solutions may be found by application of the more common laws of nature. In many cases, however, problems do not have distinct answers and therefore the value of solutions is a direct function of the member's own interest and background. As may be realized, the overall picture is one of learning more thoroughly what has already been learned and of advancing one's knowledge in any field of particular interest.

Background is acquired faster

Most engineers agree that five years of experience in industry are required for the college graduate to become truly productive. This generally pertains to the period necessary to acquire a sound background and proper perspective.

By working problems presented by various departments instead of textbook versions of the same, members of the Engineering Technical Course obtain the necessary background more quickly. In most cases, problems are the "hard nuts to crack," and being close to such problems is excellent training for engineering work. Problem presentation by chief engineers and engineers-in-charge provide a most effective means of helping the students gain the required perspective. Members of each class are treated as an engineering group responsible to the engineers presenting the problem. The atmosphere is one of doing a project for a different product department each week.

How the engineer conceives, understands, and solves a problem constitutes his engineering philosophy. Members of the ETC are given numerous opportunities to observe and understand the philosophy of successful engineers. Their own patterns can therefore be established with a solid foundation at an earlier date than would otherwise be possible.

From the very conception of a problem, each engineer views it in a different light. Some may doubt that a problem exists while others may consider it a very involved type. Both may be perfectly right in their analyses. For example, a device may have a part that wears out periodically. One engineer may consider this no problem, just a matter of designing for ease of replacement. Another may consider it a design weakness and try to lessen frequency of replacement or eliminate it altogether. The approach to any given problem varies with individuals; methods of solution range from use of standard formulae to complex analyses in differential equations. The method of establishing a valid set of assumptions as well as the degree of accuracy likewise varies with different engineers. The value of the answer, its check verification and usage, constitute additional differences.

Although engineering problems vary considerably and there are always new and different conditions, one goal of the Engineering Technical Course is to prepare its members with a sound engineering philosophy. Most members not only accept challenging problems but actually invite them.

Creativity learned and practiced

Approximately 20 percent of the ETC program is devoted to encouraging creativity. Although all engineering prob-

lems entail a certain amount of inventiveness, some are selected for the ETC especially because they are basically creative. It is from the review and discussion of these problems that each member can evaluate and improve his own creative ability.

Brainstorming or creative sessions are conducted in accordance with the recommendations of Alex F. Osborn, related in his book *Applied Imagination.*

Conducted periodically, creative sessions have the following ground rules:

A. Assume every idea will work — outlaw criticism and evaluation during session — judgment day comes later.

B. Search for ideas without restrictions — the wilder, the better.

C. Seek quantity, not quality. The more you fish, the better the chances for landing the "big ones."

D. Combine and improve previous ideas — hitchhike.

Sessions are 15 to 40 minutes long, depending upon the subject, and 30 to 80 ideas are derived from each session. An example of one topic that was brainstormed, based on an inquiry received by the company, follows:

Problem: Devise a mobile device to:

a. Remove all loose particles of sand and dirt from a concrete runway.

b. Remove all metal pieces from a concrete runway.

Considerable damage is caused to jet aircraft engines by loose debris sucked into the compressor inlet from runways during taxiing and take-off operations.

A unit to remove this debris must be highly mobile, operated only between flights to keep the runway clean.

(A jet aircraft runway cleaner eventually may be used by every major airport in the world, including all military airfields.)

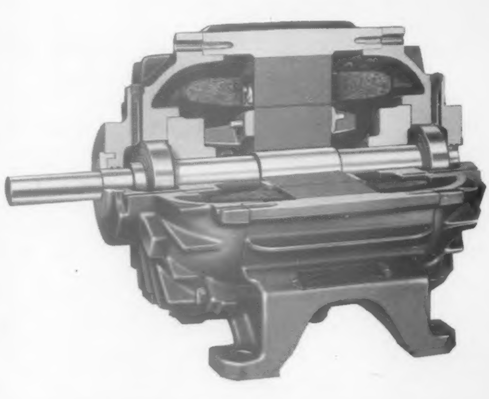
Of the 80 ideas derived from the session, several were worthy of consideration. Three suggested were:

1. Spray with a plastic and then roll up the plastic as a sheet which may be processed and reused.

2. Use a streetsweeper combined with a powerful vacuum cleaner.

3. Charge the particles, and use the opposite charge to pick them up.

Since problems are usually of a technical nature, there



FORMULAS FOR THE SLIP of the induction motor, considering the importance of this characteristic, are not very numerous. Almost any machinery textbook will give the following four formulas:

1. $I_2 = \dfrac{E}{\sqrt{\left(\frac{r_2}{s}\right)^2 + x_2^2}}$

2. $T_d = \dfrac{7.04\, m_1 I_2^2 r_2}{n_s \cdot s}$

3. $P_d = \dfrac{n\, T_d}{5250}$

4. $s = \dfrac{n_s - n}{n_2}$

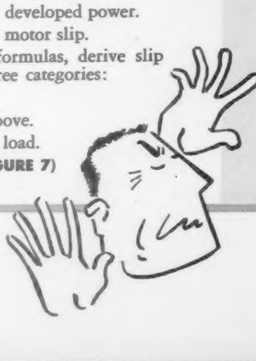
where:

I_2 = current in amperes.
T_d = torque in ft-lb.
P_d = developed power.
s = motor slip.

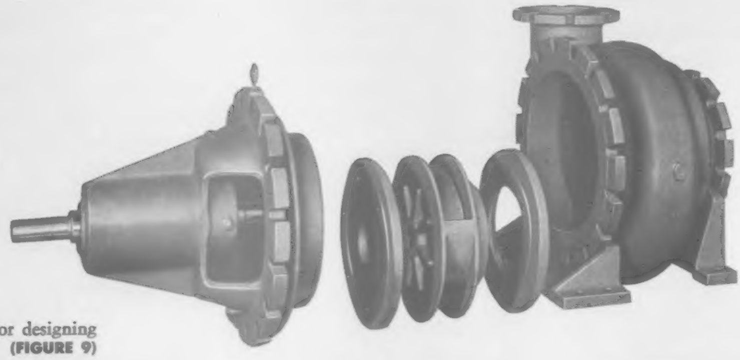
In addition to these published formulas, derive slip equations applicable for these three categories:

(*a*) Very small slips.
(*b*) Slips around full load and above.
(*c*) Slips considerably above full load.

(FIGURE 7)



IN PRODUCING CEMENT, a fundamental operation incorporates the rotary kiln. One of the major factors in maintaining high kiln efficiency is effective use of heat. At the proposal stage, the customer is given an expected value of Btu per barrel for the particular kiln proposed. It is the job of the designer to insure that heat requirements will not exceed the proposed value. Determine if an 11-foot 3-inch diameter by 400 feet long wet process kiln will meet its proposed heat requirements of 1,100,000 Btu per barrel. **(FIG. 8)**



DEVELOP A TECHNIQUE for designing centrifugal pump volutes. **(FIGURE 9)**

are fewer ideas than would normally be derived from a semi or non-technical topic. The majority of topics concern basic development or design in engineering one of the various products. A day or two after the session, lists of the ideas gathered are distributed to the members and they are asked to add any additional ideas they may have. These are returned to the coordinator who compiles a final list for submitting to the product department concerned with the problem.

Since more than 1600 different product lines are engineered and produced by the company, many diversified problems are solved each day. These problems are ideally suited to form the basis of the Engineering Technical Course.

Value of engineering breadth demonstrated

Because of this great diversification, entire installations are sometimes supplied. For example, an entire cement plant may be supplied. Components designed and manufactured for inclusion in cement plants may include crushers, screens, kilns, air quenching coolers, motors and engines, pumps, control systems, switchgear, transformers, steam turbines, generators, and others.

Typical of problems presented to the group is Figure 10. The problem statement is given to the students before the class session. Knowing the problem, students are able to review background material and equip themselves to better understand the complete problem presentation. Additional information and understanding results from the one-hour problem presentation.

Through the engineering technical program, the young engineer works directly for and learns directly from many chief engineers and supervisory engineers. By discussing his solutions with these established engineers, he gains in technology as well as scope while acquiring a philosophy. In short, his performance is judged in the spirit of helping the young engineer. The student's performance is, of course, a direct function of his own interest and initiative. The time he spends in study is an investment which may very well pay high dividends in terms of a successful engineering career.

Through this course and other courses of the graduate training program the engineering graduate gains a first hand knowledge of specific engineering problems existing in numerous industries. He sees the breadth of engineering in action and the importance of design detail. This experience enables him to learn not only about engineering but about himself. In finding the degree of specialization he wants and the function he wishes to perform, the young engineer also finds himself. He undertakes genuine engineering responsibilities quicker and with a greater degree of assurance than would otherwise be possible.

ARC FURNACE CONTROL PROBLEM PRESENTATION

A TYPICAL ARC FURNACE schematic is shown as Figure 10*c*. The carbon electrodes, which weigh about 9 tons each, are raised and lowered individually to control the current in each phase. It is desirable to keep the current constant. However, as the metal is melted down, a cave-in may occur, causing an electrode to be short-circuited, an arc to be extinguished or the arc length to change. Movement of the electrode is then necessary to establish normal conditions.

The time required to move the electrode is important, since one phase may be short-circuited or the furnace may be operating single phase following a cave-in.

To determine the response time of this type of system is difficult because of non-linear characteristics of the arc. However, an open-loop response will yield the significance of the time constant of the first amplifier. At present, a rotating amplifier with a field time constant of .35 seconds is used for the first amplifier. Determine if the time for the motor to reach full speed, with twice normal generator field voltage, will be significantly lowered if a magnetic amplifier with a time constant of about .035 seconds replaces the existing amplifier.

This problem would normally be solved with the aid of the electronic differential analyzer. You may either specify the complete computer setup or determine the solution analytically. **(FIGURE 10a)**

IN ADDITION to the written problem presentation, typified by this figure, a one-hour oral presentation and informal discussion assures that each student understands the problem thoroughly. **(FIG. 10)**

GENERAL DATA

1. Weight of electrodes, mast, arms, and cables . . . . .37,000 lb.
2. Rope pull on drum using a two part line . . . . .18,500 lb.
3. Cable drum pitch diameter . . . . .21 in.
4. Gear reducer ratio .320:1.
5. A double worm reducer is utilized. Assumed conservation gear efficiencies: running . . . .58%, breakaway . . . .36%.
6. Calculated torque required to raise the electrodes at
   100% efficiency referred to the motor shaft. . . . . 50.5 ft-lb
   58% efficiency referred to the motor shaft. . . . . 87.2 ft-lb
   36% efficiency referred to the motor shaft. . . . . .140.5 ft-lb
7. Electrodes are powered by a 725-rpm base speed, 15-hp, 230 volts dc shunt motor. The field is separately excited at rated excitation. Electrode speed is 6 fpm.
8. The motor power is provided by a 10-kw, 230 volts dc shunt generator driven by a constant speed motor. Field excitation is 120 volts.

	Motor	Generator
Armature Inductance	.01265 henrys	.010 henrys
Armature Resistance*	.308 ohms	.37 ohms
Field Inductance	.90 henrys	1.14 henrys
Field Resistance*	184 ohms	10.3 ohms
Wk^2	10 lb-ft²	

* Armature and field resistance measured at 75 C.

FIGURE 10b

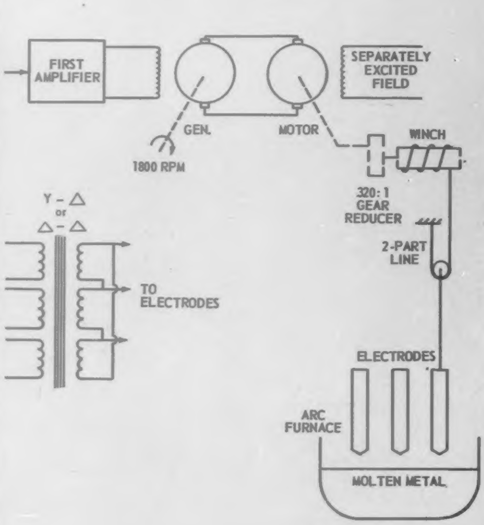


FIGURE 10c

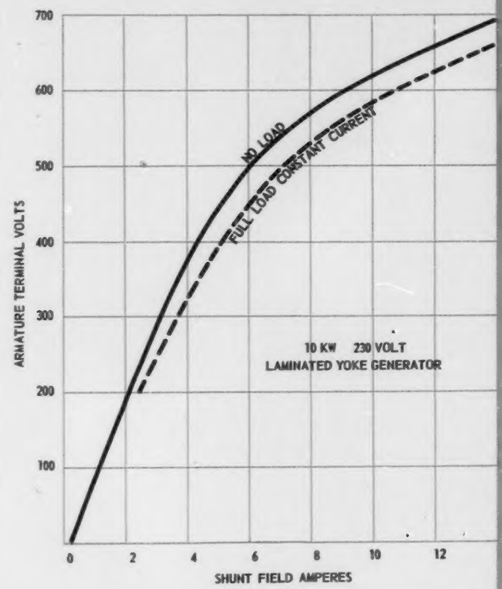


FIGURE 10d

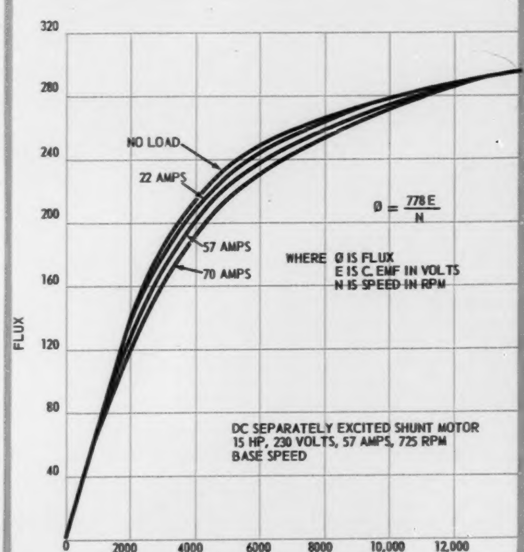
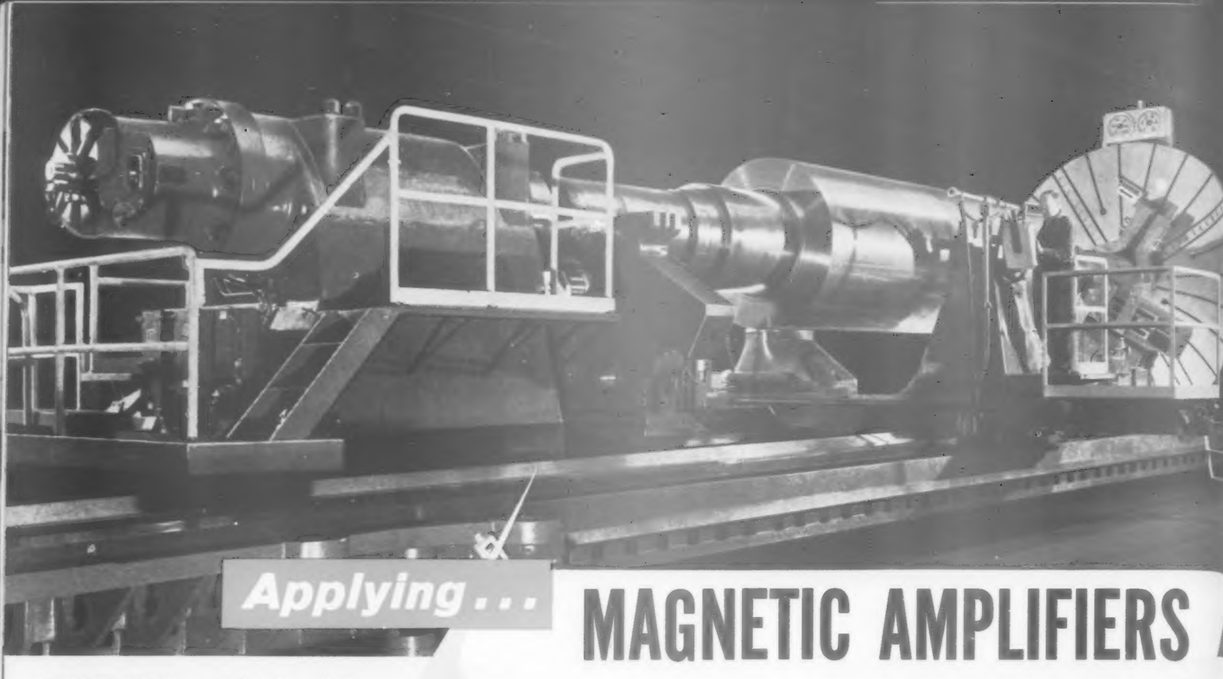


FIGURE 10e

DESTINED TO DEVELOP 175,000 kw — this rotor forging for the completely supercharged 3600-rpm generator of a 300,000-kw close-coupled, cross-compound steam turbine-generator unit is shown on the special rotor slot milling machine.


INGERSOLL
INGERSOLL



Applying . . . MAGNETIC AMPLIFIERS

VARIABLE-SPEED control for the spindle drive on this 144-inch engine lathe is one of several power applications described.

by **W. F. EAGAN**
Control Department
Allis-Chalmers Mfg. Co.

Control of power equipment and basic theory are correlated in this article.

PROBABLY NO OTHER CONTROL DEVICES have ever received a more rapid acceptance than magnetic amplifiers. Since World War II, these devices have been widely applied in industrial and military equipment.

As is characteristic of other amplifying devices, magnetic amplifiers are capable of modulating large amounts of power in response to small control signals. Tiny outputs of photocells, thermocouples, vacuum tubes, and small relays are used to govern the delivery of thousands of horsepower. Extremely fast response and a high degree of accuracy characterize magnetic-amplifier regulating systems.

Their rapid acceptance stems chiefly from their reliability. Because there are no moving parts or electronic tubes, maintenance problems for these units are virtually nonexistent when the units are properly applied.

Voltage, current, speed, torque, position, frequency, and tension are only a few of the quantities that can be controlled with magnetic amplifiers. Applications of these devices have been made in almost every industry, and they now govern many of the functions formerly controlled by rotating and electronic amplifiers as well as mechanical regulators. In other applications magnetic amplifiers supplement rotating amplifiers and electronic controls, and thereby extend the application possibilities of these well-known devices.

The following list of applications indicates their potential:

Rolling mill control for:

- Blooming mills, cold reversing mills, tandem mills, processing lines, Sendzimir mills, temper mills, and table drives.

Voltage regulators for:

- Turbine-generators, hydro-generators, diesel generators, and special military applications.

Miscellaneous regulators for:

- Cement kiln drives, sawmill carriage drives, mercury arc rectifiers, paper industry applications, engine starting and maintenance of jet aircraft, package drives, arc furnace control, mine hoists, and power-factor regulators.

In their simplest form, magnetic amplifiers are in reality saturable reactors. The advent of new core materials and new developments in metallic rectifiers brought about wide use of self-saturating circuits.

By considering a number of typical applications in various industries where mechanical, rotating amplifier, or electronic regulators have been applied in recent years, the advantages of magnetic amplifiers can be shown for a variety of functions.

Magnetic amplifiers are widely applied

Magnetic-amplifier type static regulators are being applied to a wide variety of small ac and dc motor-generator sets

What they are

and diesel generators. While in some cases the amplifier operates into the field of a conventional dc exciter, in other applications the magnetic amplifier replaces the exciter and thereby eliminates exciter commutator and bearing maintenance. Two types of military generator controls serve as examples of such applications.

Dc generators

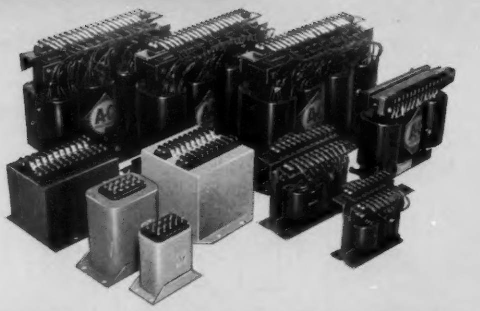
In one type of control for small machines, static regulators are used with 28-volt, 30-kw dc generators. These generators are driven by induction motors and supply maintenance and engine-starting power for jet aircraft. This equipment is often mounted in trailers for ease of transportation.

Field excitation for the generator-regulating system is provided by a three-phase magnetic amplifier. A diagram of the regulator is shown in Figure 1. The ac power for the amplifier comes from the 60-cycle source supplying the induction motor. The output voltage of the generator is sensed by means of a comparator or voltage error detector made up of linear resistors connected in a bridge circuit with nonlinear resistors, which are actually light bulbs. The bridge is so designed that the nonlinear resistors run at half their rated voltage, resulting in almost infinite life. Since their filaments operate at a sufficiently high temperature, they are unaffected by changes in ambient temperature. The comparator characteristic is shown in Figure 2.

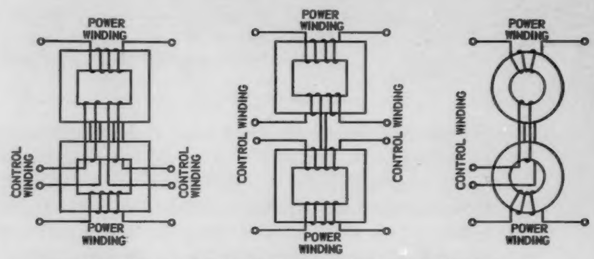
Because the nonlinear element resistance increases with voltage, there is a value of voltage at which the bridge will be balanced. Increased generator voltage above this value results in a change in control winding current in a polarity which reduces the generator excitation supplied by the magnetic amplifier. Any reduction in generator voltage causes an opposite effect in order to raise generator excitation. The generator voltage is plotted as a function of the magnetic-amplifier voltage control winding current for no-load and full-load conditions. The comparator characteristic is superimposed upon these two curves, and the resulting voltage is determined by the intersection of these curves. Voltage regulation is determined by the difference between the voltage as indicated at point *a* and the full-load voltage as indicated at point *b*.

To compensate for voltage drop in the generator output power cables, a measure of load current is taken by means of the interpole voltage drop and introduced into a cable drop compensation winding. As load increases, additional excitation is thus introduced through the amplifier, resulting in a rising voltage characteristic at the generator terminals. Cable end voltage is thereby kept essentially constant with load.

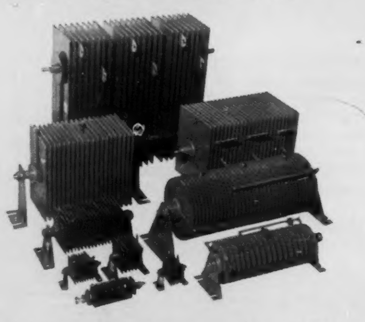
The system is kept from oscillating or having excessive overshoot of voltage during load changes by means of a rate of change signal from the generator field voltage which is fed back through a series resistor-capacitor network into a damping winding.



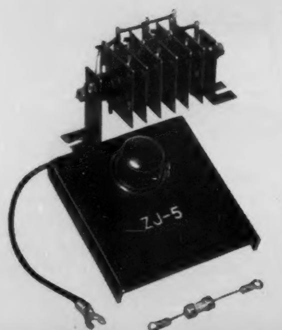
RELIABILITY, the chief reason for the rapid acceptance of magnetic amplifiers, results from the use of such simple static components as reactors, rectifiers, resistors and capacitors. The reactors, though similar to dry-type transformers in appearance, have several distinctive design features. The iron cores are wound with power windings and one or more control windings.



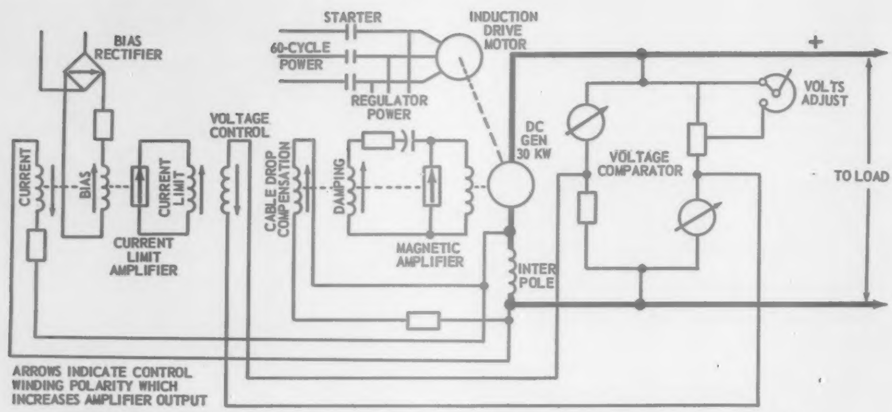
ANY NUMBER of control windings can be used, and as many as seven isolated signals are often introduced. Grain-oriented steel is used for cores of larger units, while small high-gain preamplifiers utilize special magnetic alloy steels containing large percentages of nickel. Ideally, cores are of gapless design. Many high performance cores are actually strip-wound toroids or are stacked in gapless rings. Larger cores are stacked with minimum reluctance joints to take advantage of the grain orientation of the core material. Amplifier reactors are often embedded in plastic as a protection against moisture and dirt.



STANDARD SELENIUM RECTIFIERS are widely used in magnetic amplifiers because of their history of reliable operation. While vacuum tube rectifiers could be used, the selenium types are generally preferred for industrial use. They are available in a large variety of ratings to suit the range of amplifier sizes.



GERMANIUM AND SILICON rectifiers are now being used in applications requiring extremely low leakage, low forward voltage drop, and minimum size and weight.

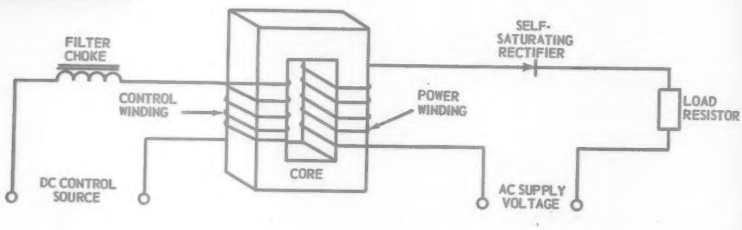


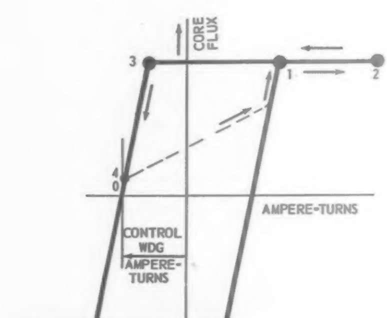
CURRENT-LIMIT and cable-drop compensation are included in the regulating system for ground power supplies used for engine starting and for checkout of the complex circuits of modern aircraft. **(FIGURE 1)**

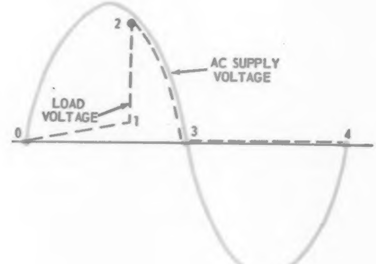
Protection against excessive currents during the starting of jet engines is provided by a second magnetic amplifier biased well into its cutoff region, as shown in Figure 3. A signal proportional to load current is fed into a second winding from the generator interpole. This signal is in a polarity that opposes the bias signal. As load current increases until the current winding ampere-turns approach those of the bias winding, the current-limit amplifier suddenly increases output with further generator loading. The output of the current-limit amplifier opposes comparator output under this condition. This arrangement limits generator output sufficiently to maintain a safe value of current during acceleration of the jet-engine starting motor. Thus the starting motor accelerates smoothly on constant current and runs on constant voltage without contactors or relays. The resultant static characteristic of the regu-

How they work

MAGNETIC AMPLIFIERS, in their simplest form, could consist of a single core assembly and a rectifying element. Alternating currents induced in the control winding by transformer action from the power winding may be suppressed by a filter choke.







CORE MATERIAL for the reactor is assumed to have an idealized hysteresis loop. An operating point 0 can be established at any point on the saturation curve by dc ampere-turns in the control winding. As the ac applied voltage increases on its positive half cycle, an opposing and almost equal instantaneous voltage is induced in the power winding over that portion of the cycle during which flux changes from point 0 to 1.

LOAD CURRENT during this portion of a cycle is at a low magnetizing value. Since the flux cannot change during the portion of the cycle where the operating point travels from point 1 to point 2, almost all the supply voltage appears across the load and load current is determined by the load resistance in this idealized case.

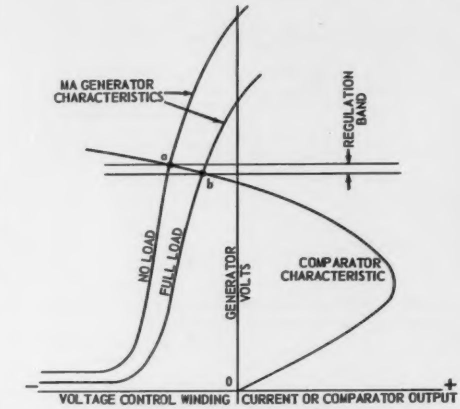
lated generator is shown in Figure 4.

Ac generators

A typical magnetic-amplifier regulator applied on an engine-driven synchronous generator is shown schematically in Figure 5. This set, rated at 90 kva, 208/120 volts, 400 cycles, was designed for use as a ground support for B-52 jet aircraft. Checkout and maintenance of electronic instrumentation on such aircraft require close regulation and fast response from the voltage-regulating equipment.

Excitation for the generator comes from a three-phase power amplifier operating on ac power from a small 400-cycle pilot alternator. Bias for this amplifier drives it to beyond maximum output. The preamplifier output opposes this bias. A static network, consisting of a saturating transformer, capacitor, resistors, and rectifiers, makes up the voltage comparator for this system. This network has a characteristic similar to that of the comparator used on the dc generator system and is virtually independent of frequency changes. The output of the comparator feeds a control winding in the preamplifier. Damping of the system is provided by means of an RC network, an arrangement similar to that used in the dc regulator.

The use of 400-cycle power for the amplifiers results in extremely fast voltage recovery, as shown in the oscillogram of Figure 6. The regulating equipment is illustrated in Figure 7.

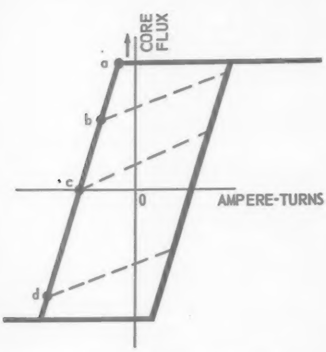


COMPARATOR CHARACTERISTIC based on combination of linear and non-linear resistors in a bridge circuit is fed into the amplifier winding. **(FIGURE 2)**

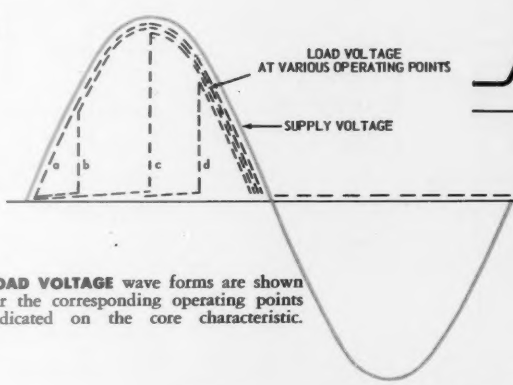
New reliability for turbine-generators

The fast response and high degree of reliability realized with magnetic-amplifier equipment make the device a logical component in excitation systems for both steam and hydraulic driven generators. While several arrangements of amplifiers and conventional dc exciters have been

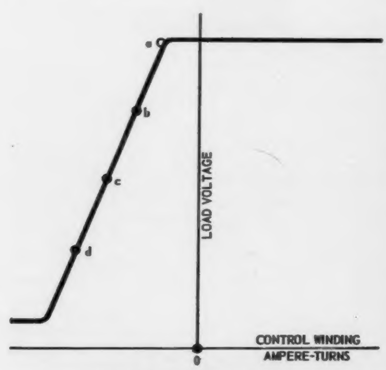
Output characteristics



EFFECT of changing the operating point by means of the control winding ampere-turns is shown by *a*, *b*, *c* and *d*.



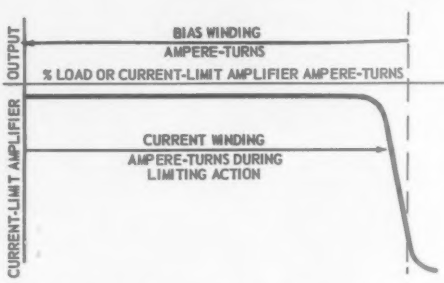
LOAD VOLTAGE wave forms are shown for the corresponding operating points indicated on the core characteristic.



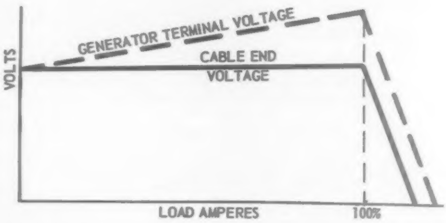
CORRESPONDING VALUE of dc output voltage for each point is indicated by the curve of load voltage.

As the control current changes to establish point *a* as the operating point, very little of the positive half cycle of supply voltage appears across the power winding and almost all appears across the load. If the operating point is established at point *d*, a larger change in flux is possible so that almost all the positive half cycle of voltage appears across the power winding and only a small portion appears across the load. The self-saturating amplifier thus operates similar to a grid-controlled thyratron.

The output characteristic resulting from this action is shown by the load voltage curves. If several control windings are used, the operating point is determined by the algebraic sum of the ampere-turns in the various windings.



CURRENT-LIMIT AMPLIFIER prevents excessive starting by limiting generator output. **(FIGURE 3)**



COMBINED current-limit and line-drop compensation features provide desired output characteristic. **(FIGURE 4)**

applied, one of the most interesting of these is the new Allis-Chalmers inductor alternator excitation[1] system.

The operating principle of the inductor alternator system is based on the use of magnetic amplifiers. The system consists of a 420-cycle inductor alternator whose output is rectified in order to obtain dc for excitation of the turbine-generator. All rotating windings as well as the commutator and commutator maintenance are eliminated. A typical arrangement is shown in Figures 8 and 9.

The ac exciter is self-excited with a series field providing more than enough excitation for any desired amount of exciter output. Since the exciter has an inherently large internal reactance, the exciter output is controlled by varying shunt reactive loading provided by magnetic power amplifiers.

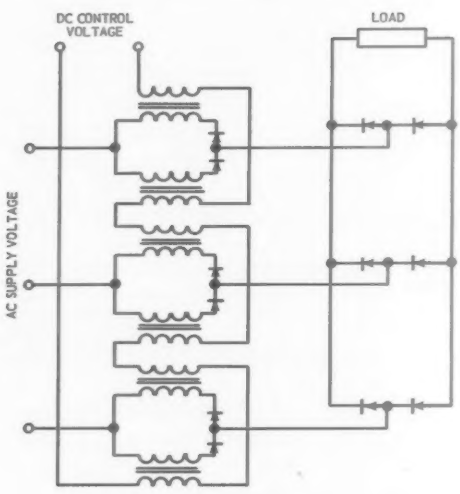
A pair of push-pull connected high-gain preamplifiers control these power amplifiers. Turbine-generator voltage is sensed through potential transformers by a comparator which operates into the preamplifier stage.

The inductor alternator system has proven to be extremely reliable and free from maintenance, with tests showing remarkably fast response. The control cubicle for the inductor alternator system is shown in Figure 10.

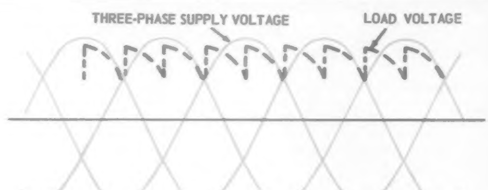
Machine tool drives offered closer control

Today, electrical drives for many types of machine tools are being regulated by magnetic amplifiers. Three magnetic-amplifier type regulators are utilized in the control

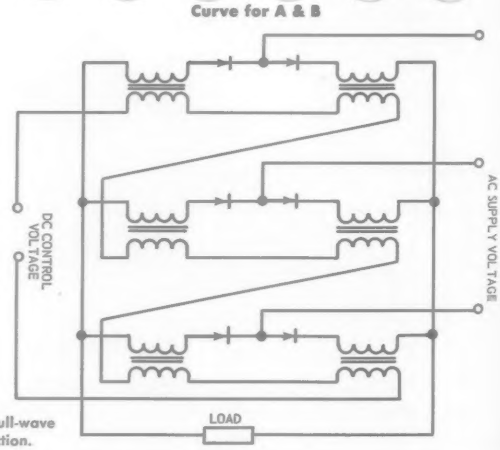
Basic circuits..



A — Three-phase ac output connection supplying bridge rectifier.



Curve for A & B

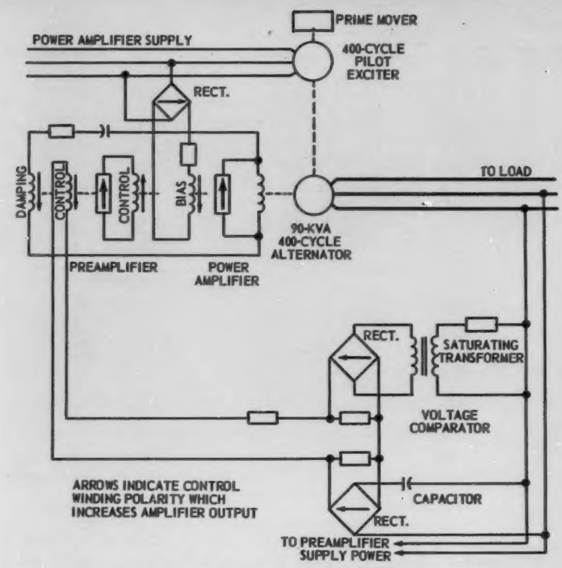


B — Three-phase full-wave bridge connection.

HALF-WAVE circuit, shown on page 22, is seldom used in actual practice. The most commonly used circuits are shown in schematic detail in diagrams *A, B, C, D* and *E*. The output wave form, corresponding to each diagram at partial output, is also shown.

system for the 144-inch lathe shown on page 20. They are: a spindle drive generator voltage regulator, a spindle drive motor field current regulator and a carriage drive motor field current regulator. The spindle drive control is shown schematically in Figure 11. The lathe spindle speed is controlled by coordinated operation of a voltage regulator and a motor field current regulator. The 200-horsepower spindle motor is supported by a generator excited from a conventional dc exciter and a magnetic amplifier (*1MA*) that supplies field excitation to the exciter. The amplifier is biased to cutoff, and the exciter has a small bucking field which cancels the residual output of the amplifier and exciter. This arrangement prevents creeping of the spindle motor when zero speed is desired.

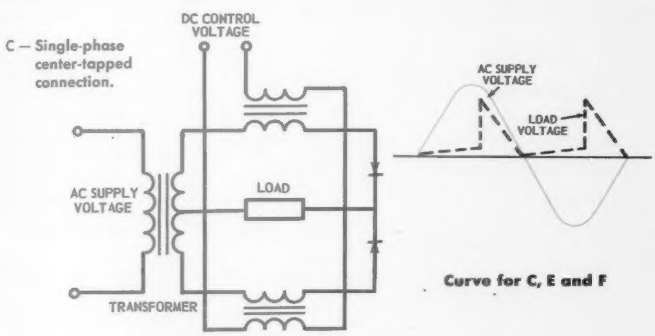
Generator voltage is set by comparing a portion of its output voltage with the voltage that is set on ring *A* of the motor-driven rheostat (*MOR*). This rheostat is connected across the control bus as a potential divider. Any difference between the reference voltage set on the rheostat and generator voltage results in a current through 1*MA* control winding which brings the generator voltage into balance with the rheostat voltage. The drive speed is proportional to this voltage. A safe rate of acceleration or deceleration is provided by the fixed operating speed of the *MOR* pilot motor. The spindle motor accelerates to any desired speed up to that corresponding to rated voltage, with full field over a portion of rheostat travel. Further travel of *MOR* results in additional acceleration to higher

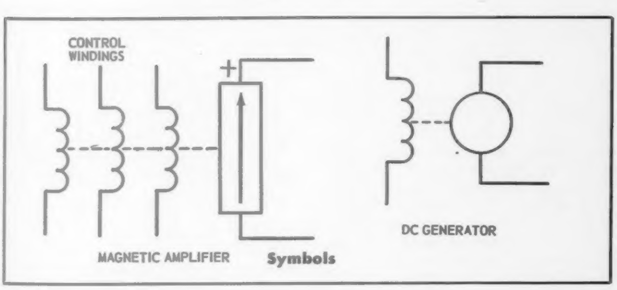


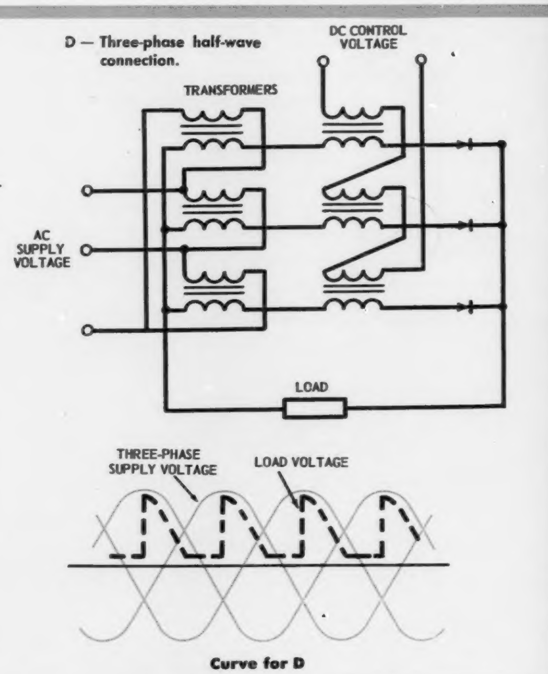
THREE-PHASE, 400-cycle system with magnetic amplifier control supplies ground support power with extremely fast response. **(FIGURE 5)**

speed by weakening the field of the motor while armature voltage remains constant.

The motor field current is regulated by means of amplifier 2*MA*, which supplies up to 5 kw of motor field excitation. Reference winding ampere-turns are determined by the position of ring *B* of *MOR*. Polarity of the reference

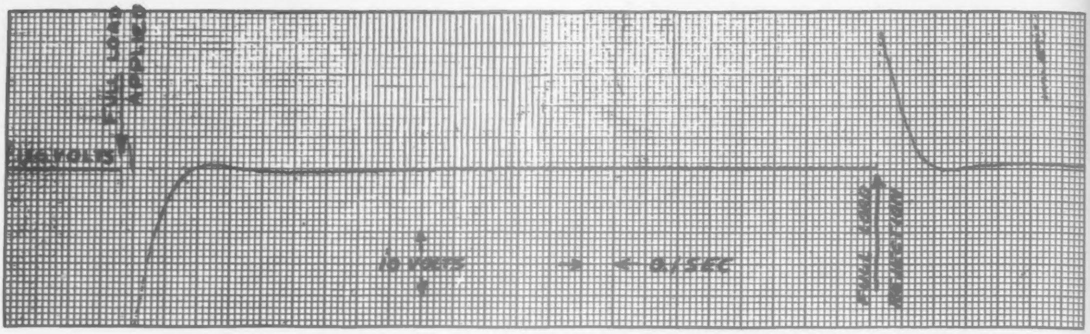






SYMBOLS simplify complex system diagrams. Corresponding to symbol for dc generator armature, the rectangle with arrow represents amplifier power circuit. Same single winding symbol used for generator field represents complex interconnection of reactor control windings.

TRANSIENT RESPONSE of the amplifier is similar in nature to that for a dc machine. Amplifier output changes very nearly exponentially for a step change in control winding voltage. Transient response is measured in terms of response time, which



OUTPUT OSCILLOGRAM of 400-cycle ground power supply generator shows 0.2 second recovery after application or rejection of load. **(FIGURE 6)**

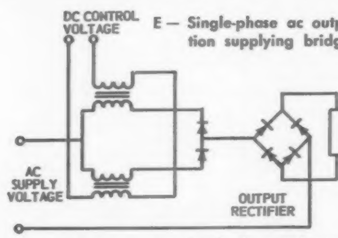
winding ampere-turns is such that it tends to increase the output of 2*MA*. The field current increases until the opposing ampere-turns in the balance winding of 2*MA* almost cancel those of the reference winding. The reference winding current is reduced during the last portion of *MOR* travel, thus reducing the field current. This field reduction results in further acceleration of the drive after rated armature voltage is reached.

When supplied with a constant armature voltage, a dc shunt-type motor drops in speed with loading. A small amount of boosting excitation is therefore provided through 1*MA* by means of an *IR* compensating winding. This winding receives a signal proportional to load current from the generator interpole. The resulting generator voltage characteristic increases with load, causing an almost flat motor speed characteristic.

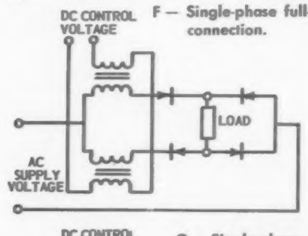
Any speed from zero to maximum can be set by holding in the appropriate "raise" or "lower" contacts which energize the *MOR* pilot motor until the desired speed is reached. Smooth acceleration or deceleration is assured throughout the speed range.

The lathe carriage motor is supported by an electronic thyratron power supply. A portion of the lathe speed range is controlled by means of a motor field current regulator similar to that of the spindle drive.

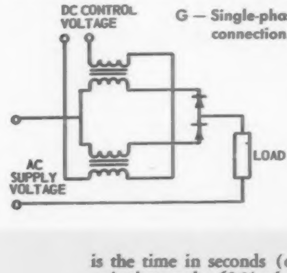
E — Single-phase ac output connection supplying bridge rectifier.

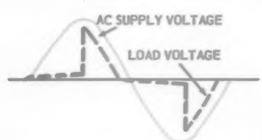


F — Single-phase full-wave bridge connection.

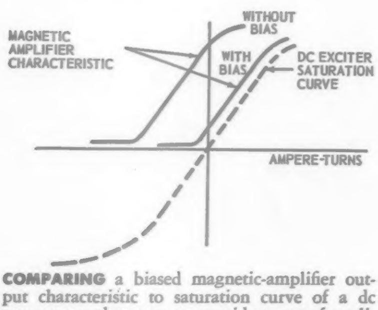


G — Single-phase ac output connection.

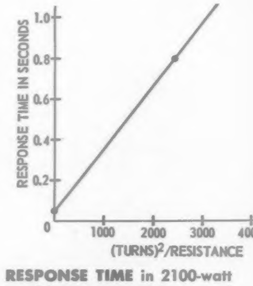




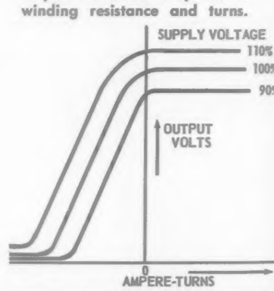
Curve for G



COMPARING a biased magnetic-amplifier output characteristic to saturation curve of a dc generator makes apparent a wide range of applications of these devices. The main differences are: (1) Output of single amplifier cannot be made to reverse by reversing control winding polarity. (2) Amplifier output cannot be reduced to zero as a result of low residual magnetizing current in the reactors. (3) Amplifier output voltage contains much higher ripple than the commutator ripple of a dc generator.



RESPONSE TIME in 2100-watt amplifier is affected by control winding resistance and turns.

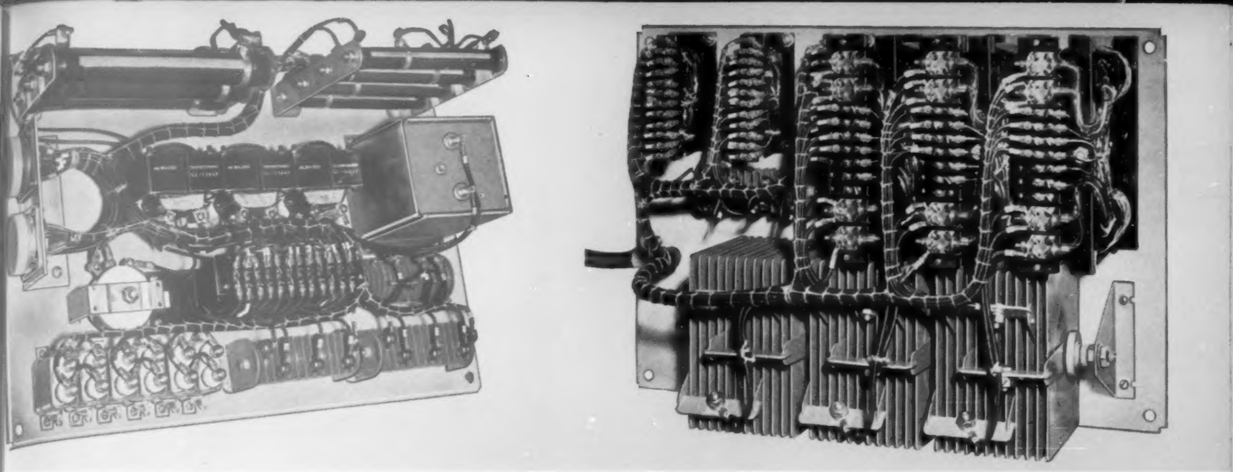


EFFECT of supply voltage fluctuations for an amplifier is similar to that of speed fluctuations for a dc machine.

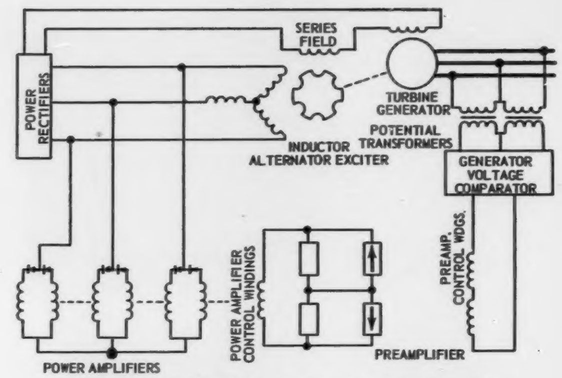
is the time in seconds (or cycles of supply frequency) required to make 63% of the total change in output when a step of control signal is applied to a control winding. Amplifier response time can be reduced by increasing the control winding resistance with an external resistor. This of course reduces the power amplification of the device.

REVERSING is obtained by one of three methods: 1, 2 or 3. Method 1 has two amplifiers biased to cutoff or up to 50% output. As one increases in output, the other reduces its output. The voltage difference across the output resistors is applied to the exciter field. Although the arrangement is inefficient, it is frequently used.

Method 2 requires two fields on the exciter. The forward am-



ALL STATIC EQUIPMENT provides most reliable regulating system known. Two panels above control 400-cycle generator. **(FIGURE 7)**

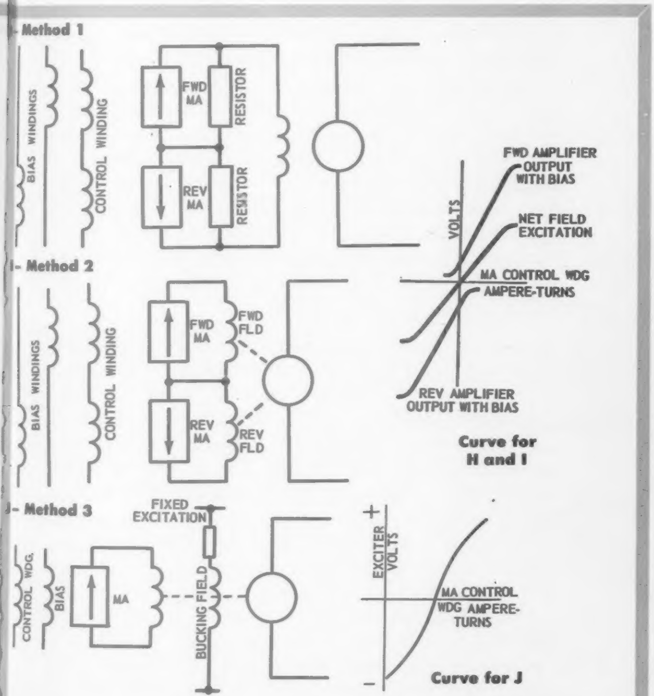


INDUCTOR ALTERNATOR systems having magnetic amplifiers now control large turbine generators. **(FIGURE 8)**

Mill production rates boosted

Higher production rates, closer tolerances on the finished product, and an emphasis on maintenance reduction are the fundamental requirements of new equipment used in steel industry production processes. The hot and cold rolling[2] of steel as well as the many finishing processes[3] offer a wide variety of applications for magnetic amplifiers. Mill-type magnetic amplifiers are shown in Figure 12.

Many processes incorporate voltage and speed-regulating systems very similar to that used for the lathe spindle drive. The dc variable-voltage control is an interesting

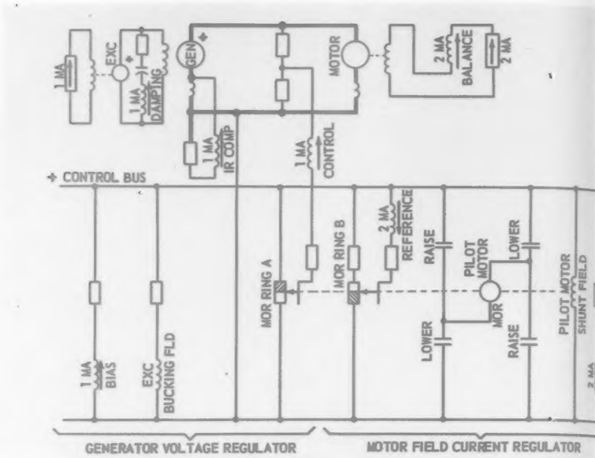


plifier is polarized to drive exciter output up, while the reverse amplifier drives output down. Method 3 requires an exciter field with a constant excitation equivalent to rated output in the reverse polarity. Only one forward amplifier is required. At 50% amplifier output the exciter voltage is zero. At maximum amplifier output a rated forward exciter voltage is obtained.

COOLING AIR for magnetic amplifier rectifiers in inductor alternator exciter system is drawn through filter, rectifier bank and duct by fan on exciter. **(FIGURE 9)**

EXCITATION CONTROL CUBICLE for system shown in Figures 8 and 9 contains all static components. The cubicle may be mounted in any convenient location. **(FIGURE 10)**

STEEL MILL ENGINEERS are showing a growing preference for magnetic-amplifier type mill control because of the marked savings they provide in maintenance and down time. **(FIGURE 12)**



SPINDLE SPEED CONTROL for one of the largest engine lathes built provides precise regulation for turning heavy forgings. **(FIGURE 11)**

system which appears frequently in temper and cold-reduction mills for winding reel drives of the type shown in Figure 13. Careful regulation of tension is necessary during the windup operation. Care is necessary in order to produce a coil that can be easily handled in future operations. It is also important to the mechanics of the rolling operation.

Windup reel

Due to buildup of steel on the reel mandrel, strip tension control is complicated by the change of coil diameter and reel motor rpm. Analysis of the problem discloses that the constant tension results in a system which delivers horsepower proportional to strip speed. Mechanical horsepower is proportional to the product of a motor counter emf and armature current. A current regulator working into the generator field regulates armature current to a value proportional to the desired value of tension. At the same time, a counter-emf regulator, working through the motor field, maintains the internal voltage of the motor proportional to strip speed as measured by the voltage of a deflector roll driven tachometer generator.

Generator current regulator

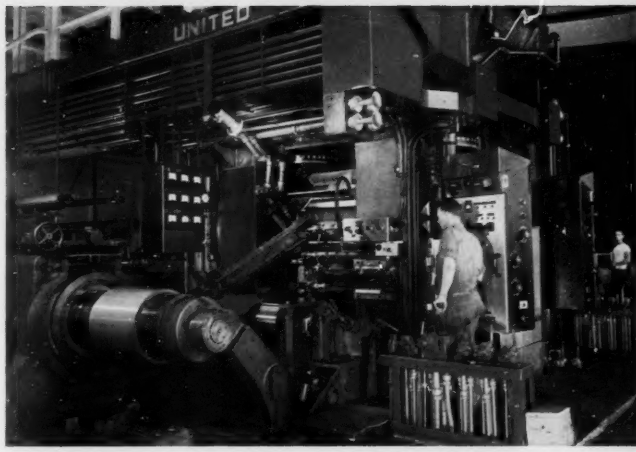
A push-pull connected magnetic amplifier supplies generator excitation through a conventional dc exciter, as shown in the diagram in Figure 14. The two amplifiers are biased negatively to cutoff or slightly above. Ampere-turns, as determined by the operator's tension-setting rheostat, are set in the reference windings, tending to drive generator voltage upward. Armature current will therefore increase until the ampere-turns of the balance windings almost cancel those of the reference winding. Balance winding ampere-turns are proportional to armature current as determined by the generator interpole drop. The operator sets the value of the armature current by setting the tension rheostat. The generator voltage will be maintained at a value greater than the motor counter emf by an amount equal to the armature circuit *IR* drop. A conventional RC damping circuit provides system stability and response.

Counter-emf regulator

The motor counter emf is regulated by a rheostatic-type regulator. The desired strip speed, and hence motor rpm, is determined by the speed of the work rolls in the last stand of the mill. The motor internal voltage for a given strip speed is therefore dependent on the motor field current, which is set by a motor-operated rheostat (*MOR*) in order to maintain constant horsepower. Since armature current is maintained by the generator current regulator, it is necessary that the voltage be proportional to strip speed. The rheostat pilot motor is energized by a magnetic amplifier which is biased to cutoff. As the coil builds up, the reel motor tends to slow down and reduce its internal voltage. The motor internal voltage becomes less than tachometer voltage, causing amplifier control winding current to flow. This current increases amplifier voltage and causes the pilot motor to advance the rheostat, thereby increasing motor field current and hence motor counter emf. A small signal, proportional to armature current obtained from the motor interpole drop, is also injected into the amplifier to correct the system error caused by the necessity of sensing motor terminal voltage rather than internal voltage. The motor-operated rheostat allows the system to hold the proper field current setting for a given coil diameter when the mill is stopped. Maintaining field current at the value corresponding to the existing coil buildup provides tension control should the mill be stopped for any reason before the coil is filled.

Inertia compensation

Constant current regulation is satisfactory when the mill is running at constant speed, but mechanical inertia causes an undesirable tension error during acceleration or deceleration of the mill. Mill speed, as determined by the work roll drive motor, is set by a system giving a fixed linear acceleration rate, as shown in Figure 15. The armature current is regulated to give the desired tension before and after acceleration. During acceleration the *ACC* contact closes and provides additional ampere-turns which aid those of the reference winding. These additional ampere-turns result in a higher motor current and the extra torque necessary to overcome mechanical inertia. This tends to hold strip tension constant during the accelerating period. During deceleration the intertia-compensating ampere-turns are reversed when the *DEC* contact is closed, and tension is held while the mill slows down.

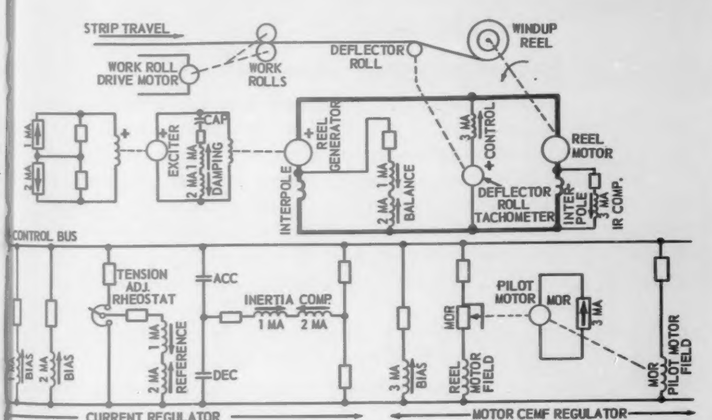


STRIP TENSION is held constant through magnetic-amplifier control of the windup reel motor in this reversing mill. **(FIGURE 13)**

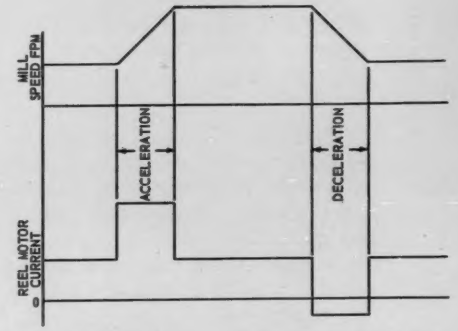
[1] "Commutatorless Exciter Works Well," H. Roth and W. C. Kaldenberg, *Electrical World*, May 28, 1956.

[2] "Magnetic Amplifiers on a High Speed Accuracy Single-Stand Reversing Mill," Al Mozina, *Blast Furnace and Steel Plant*, June 1956.

[3] "Controlling Process Lines for Transformer Steel," E. F. Boening and J. Kostelac, *Electrical Review*, 4th Quarter, 1955.



PUSH-PULL connected amplifier is used as pilot exciter in the current regulator circuit of the reel motor generator. **(FIGURE 14)**



REEL MOTOR CURRENT is regulated to preset values during acceleration and deceleration to provide compensation for the heavy mechanical inertia of the mill. **(FIGURE 15)**

Choosing Protection For Transformer Oil

by **L. W. SCHOENIG**
Transformer Department
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Here are the pros and cons of the basic transformer oil protective schemes.

THE CHOICE of a transformer oil protective scheme is important if the transformer insulation and cooling are to be effective through long years of service. Although oil is relatively stable, its chemical and physical qualities can be seriously affected by its operating temperature as well as by moisture and oxygen absorbed from the air.

Oil temperature is a function of the load applied to the transformer, the ambient temperature of the cooling medium, and the design of the unit. To obtain maximum oil life in a power transformer, the oil temperature should not exceed 85 C. The rating of a transformer should be carefully considered in the light of ambient temperature and load to insure a reasonable operating temperature of the oil.

The effect of moisture on one of the most important characteristics of oil, its dielectric strength, is shown in Figure 1. Only an extremely small amount of water in suspension in the oil reduces the dielectric strength below a safe value.

One reason why transformer engineers worry about oxidation of transformer oil resulting from prolonged contact with air at high operating temperatures is the sludge which can clog cooling ducts in the transformer. Furthermore, if the oil is allowed to oxidize, it tends to become slightly acid. This reaction reduces the dielectric strength of the oil and causes oxidation of the other organic insulation in the transformer.

To prevent oil contamination, some form of oil protection should be used with each transformer. There are three basic oil protection schemes designed to keep both air and moisture from coming into contact with the oil. In protecting the oil, the system must allow for oil expansion and contraction resulting from normal changes in load and ambient temperature. The three basic systems are:

1. Conservator or oil expansion tank system.
2. Sealed tank construction.
3. Inert-gas sealed systems.

PRESSURE INERT-GAS SYSTEM protects the oil in 230,000-kva, 161-kv transformer at TVA's Kingston Generating Plant. The small nitrogen supply cabinet mounted at the end of transformer tank does not interfere with the high voltage lines or bushings.

Conservator system allows expansion

The oldest form of oil protection is the conservator or oil expansion tank system. The general arrangement of the component parts is shown in Figure 2. To function properly, the conservator tank must be located at an elevation higher than the main tank. The main tank, which is completely filled with oil, is connected to the expansion tank by a relatively small pipe. Expansion of the oil in the transformer because of increased load or ambient temperature causes the oil to rise through the connecting pipe into the conservator tank. Since the oil in the main tank is under pressure from the expansion tank, contraction of the oil in the main tank because of decrease in load or ambient temperature causes the oil in the expansion tank to return to the main tank.

The volume of the oil expansion tank is approximately 10 percent of the oil volume in the transformer. With this

relationship, the oil expansion tank will operate satisfactorily over a temperature range of —10 C to 85 C.

The advantages of the conservator system are:

1. Simplicity of operation.
2. Decreased tank height.
3. Oil in main tank under pressure.

The operation of the oil conservator system is very simple, since its component parts function without complicated valving. A periodic check of the oil level gage on the conservator will determine whether the system is functioning properly.

The low oil level alarm on the oil gage can be used to indicate loss of oil before serious damage can result.

The decreased tank height is advantageous in substation design and where shipping size limitations are critical.

Since the oil in the main tank is under pressure, leaks at gaskets and welds are easily located, and air and moisture are prevented from getting into the transformer.

Disadvantages to the conservator are:

1. Location of conservator may complicate substation design.
2. Oil under pressure in main tank is a potential fire hazard.
3. Contamination of oil in expansion tank can be transferred to oil in main tank.

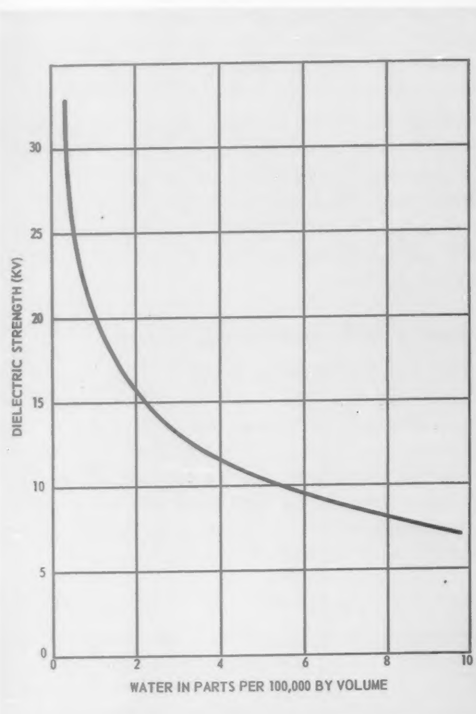
Since the conservator tank must be located at a level higher than the main tank, location of bushings, arresters, and main line leads may be a problem because of electrical clearances.

Because the oil in the main tank is under pressure, a leaky gasket or broken porcelain may permit oil to leak from the transformer. A bushing flashover under these conditions could result in a serious fire. Conservator-type transformers have been completely destroyed in fires started in this manner.

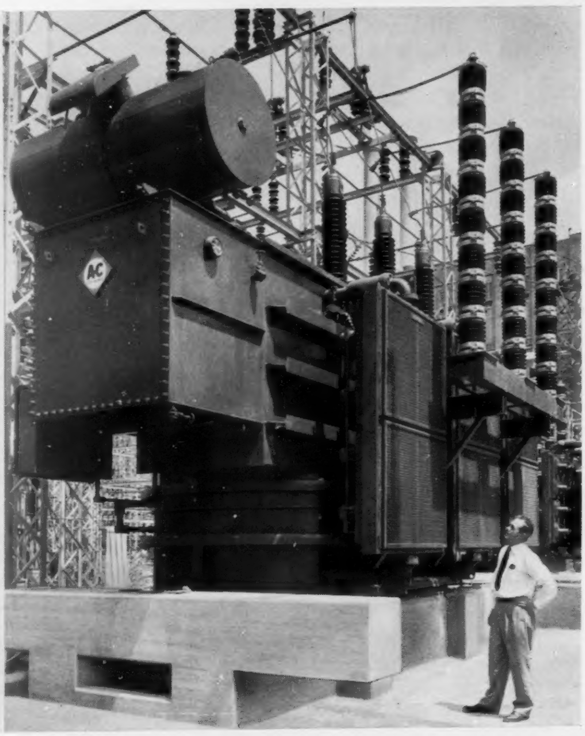
Since the surface oil in the expansion tank is exposed to the atmosphere, the oil oxidizes and may absorb moisture from the air. The oxidation of the oil in the expansion tank is slow because of the low temperature of the oil in the tank. Due to an interchange of oil between the expansion tank and the main tank, the quality of the oil in the main tank can be adversely affected.

Sealed tank system is widely used

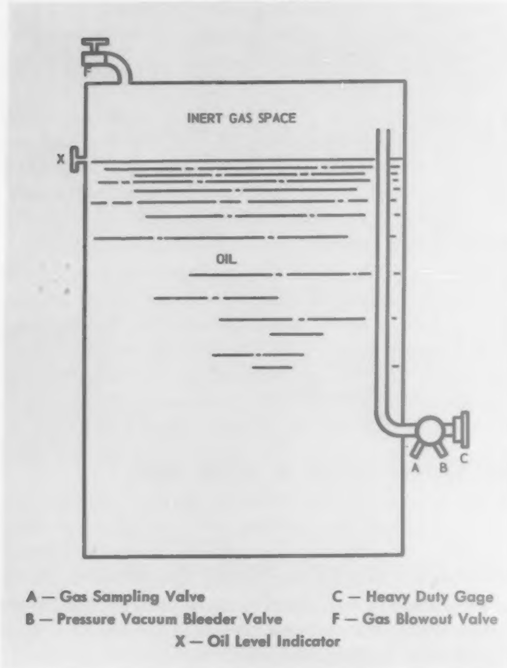
In the sealed tank system shown in Figure 3, the main tank is not completely filled with oil, and a gas space is provided to permit expansion or contraction of the oil resulting from changes in ambient and load. The volume of the gas space is sufficient to permit operation over the normal temperature range without exceeding the design strength of the tank, gaskets, and seals. For normal operation a



MINUTE PARTS of water in suspension in transformer oil seriously reduce its dielectric strength. Water absorption can be prevented in several ways. **(FIG. 1)**



CONSERVATOR or expansion tank is mounted above the load tap-changing equipment on this 75,000-kva, 115-kv power transformer. This arrangement is still widely used in Europe. **(FIGURE 2)**



SEALED TANK oil protection system used on smaller power transformers seals oil from atmosphere. **(FIG. 3)**

DRY NITROGEN in pressure inert-gas system is supplied from high pressure cylinder through pressure-regulating valves. **(FIG. 4)**

gas space of approximately 12½ percent of the space occupied by the oil is required.

To protect the transformer in the event of emergency temperature extremes, a pressure bleeder valve releases gas to the atmosphere before the pressure in the transformer tank exceeds a safe level, and admits air to the gas space before the internal pressure falls below a safe value.

The advantages of the sealed tank system are:

1. Simplicity of operation.
2. Oil is normally sealed from atmosphere.
3. No interference with bushing arresters or radiator arrangement.

The simplicity of operation is obvious, since there are no moving parts. If the normal operating temperatures are not exceeded, there is no interchange of gas between the gas space and the atmosphere. Sludging of the oil, therefore, is almost entirely eliminated. Normally, no accessory expansion tanks, control cabinets, and the like, are used with this oil protection system, so there is no interference with location of bushings, arresters, radiators, and other accessories.

The disadvantages are:

1. Size of gas space required.
2. High operating pressure.

The large size of the gas space required for successful operation increases the height of the transformer to a point where shipment by railroad might be restricted. This limitation can be overcome by the use of an auxiliary expansion tank. In view of the higher operating pressure possible with this system, there is probably a greater chance for gas leaks.

Inert-gas sealed systems use nitrogen

The main tank of the inert-gas sealed transformer, unlike the conservator transformer, is not completely filled with oil. The inert-gas system maintains, as the name implies, an inert gas, usually nitrogen, in the space above the oil. Since several methods are used to maintain the inert gas in the space above the oil, this basic method of oil protection can be divided into two types: pressure inert-gas systems and oil-sealed inert-gas systems.

Pressure inert-gas system requires nitrogen cylinder

The pressure-type system utilizes DRY nitrogen from a high pressure cylinder to maintain an inert gas in the space above the oil. Equipment for this system is shown in Figure 4. The 2000-pound pressure in the supply cylinder is reduced through a series of reducing valves to approximately 5 pounds per square inch. By means of a pressure regulator, gas from the supply cylinder is admitted to the

gas space when the pressure in the gas space falls below a minimum value. In like manner, gas is released to the atmosphere if the gas space pressure exceeds a maximum value. With this system the gas space is approximately 8 percent of the oil volume.

The advantages of the pressure-type inert-gas system are:

1. Gas in space above the oil is always under pressure.
2. No interference with bushings, line leads, or radiators.

Since the gas space above the oil is always under pressure, air cannot come into contact with the oil. Sludging of the oil is therefore kept to an absolute minimum. If a leak occurs, no air or moisture will be drawn into the transformer. An oil or gas leak is indicated by either oil streaks or a loss of nitrogen alarm.

Although the pressure inert-gas transformer is somewhat taller than a conservator unit, no problems of bushing arrangement, line lead clearance, or radiator arrangement are introduced, since the only equipment required for the oil protection is a relatively small cabinet housing the pressure-regulating equipment and the nitrogen supply.

The disadvantages are:

1. Pressure system is somewhat complicated.
2. More inspection and maintenance required.

Complicated valving is required in the pressure-regulating system to decrease the supply pressure from 2000 to 5 pounds per square inch and to maintain a pressure of approximately ½ to 5 pounds per square inch in the gas space. Because of the pressure-regulating equipment and the necessity of changing nitrogen cylinders occasionally, periodic inspection and maintenance must be scheduled. The number of inspections required for this system is probably somewhat greater than for the other systems.

Oil-sealed inert-gas system uses divided tank

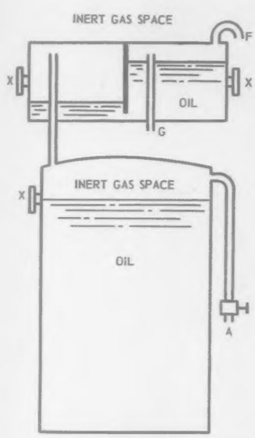
The oil-sealed inert-gas system, shown in Figure 5, maintains a nitrogen atmosphere above the oil in the main tank by utilizing a divided expansion tank. The two sections of the expansion tank are isolated by an oil seal. One section of the divided expansion tank is connected to the gas space above the oil, while the other section opens to the atmosphere.

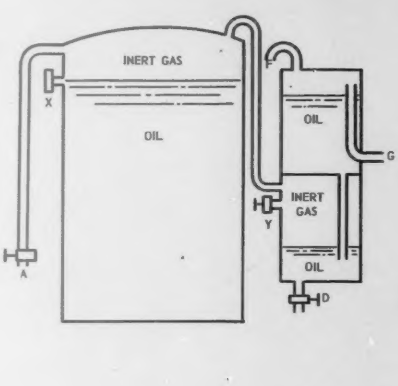
In operation, expansion of the oil in the main tank, because of increased load or ambient, or both, increases the pressure of the gas in the space above the oil. The increased pressure causes the oil in the inert-gas side of the expansion tank to lower and the oil in the atmosphere side of the expansion tank to rise. With a decrease in load or ambient the converse is true. The gas space above the oil in the main tank and the volume of the expansion tank occupies approximately 15 percent of the oil volume.

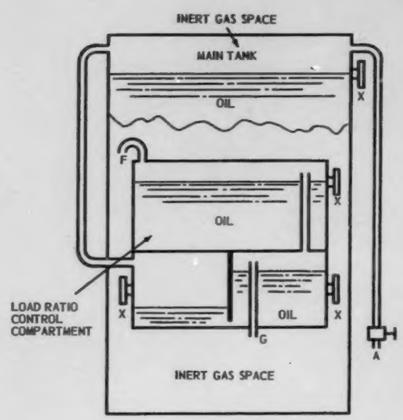
The advantages of the oil-sealed system are:

1. No interchange of oil between the expansion tank and main tank.
2. No interference with bushings or line leads.
3. No moving parts.
4. Little or no maintenance.

Although the oil in the atmospheric side of the expansion tank is subject to oxidation, the oxidized oil is not transferred to the main tank. Since there is no interchange of oil, the quality of the oil in the main tank is maintained at a high level. The expansion tank can be mounted at a convenient elevation or location, since the interchange between the main tank and the expansion tank is the inert gas and not oil. Maintenance of the oil protection system is kept to a minimum because there are no mechanical moving parts. Additional nitrogen need not be added to the system after the gas space is properly purged of oxygen.







A — Gas Sampling Valve
D — Drain Valve

F — Unidirectional Breather Outlet
G — Unidirectional Breather Inlet

X — Oil Level Indicator
Y — Filling Level Valve

MOISTURE from air is sealed from inert-gas space above oil in main transformer tank by oil in expansion tank. **(FIGURE 5)**

VERTICAL TANK is sometimes used to save space in inert-gas sealed system. Principle of operation is same. **(FIGURE 6)**

LOAD TAP-CHANGING transformers may have oil-sealed gas expansion tank mounted under tap-changing mechanism. **(FIG. 7)**

The disadvantages are:

1. Expansion tank can complicate radiator arrangement.
2. System operates at positive and negative pressures.
3. Difficult to detect leaks.

Although the location of the expansion tank is flexible, the tank is, of necessity, rather large. On large transformers, particularly where many radiators are required, the use of an oil-sealed inert-gas expansion tank poses a problem of radiator arrangement.

The pressure on the oil in the main tank is a function of the oil level in the expansion tank. If the oil level on the atmosphere side is higher than on the inert-gas side, the pressure on the inert-gas system is positive. If the oil level on the inert-gas side is higher than the atmospheric side, the converse is true. Since the expansion tanks are designed so that the difference in oil levels is small, the pressure changes in the gas space in the main tank can be limited to a rather low value. In view of the very low pressure in the gas space, it is difficult to locate gas leaks.

System variation

A variation of the oil-sealed inert-gas system is shown in Figure 6. The basic difference between this system and the usual system is that the two parts of the expansion tanks are located above one another and not side by side. This arrangement permits the use of a vertical-type expansion tank which usually requires less floor area and does not hamper radiator arrangement as much as the conventional oil-sealed expansion tank. This arrangement normally operates at a positive pressure.

In many cases where load tap-changing equipment is supplied on a transformer, the oil-sealed expansion tank is located under the LTC mechanism, as shown in Figure 7. This location is desirable because no additional floor space is required.

Choice varies with size and application

Although any of the oil preservation systems can be supplied for any individual transformer, general customer preference for the sealed tank system on 10,000 kva and smaller, 67 kv and lower transformers has led to a standardization of this system for these preferred power transformers. Figure 8 shows one of these units in a multi-circuit substation. On the larger sizes of preferred power transformers, the oil-sealed inert-gas systems, the pressure inert-gas system, or the conservator system can be supplied at no price differential.

Transformer ratings above the preferred power transformer sizes are normally supplied with oil-sealed inert-gas or pressure inert-gas equipment. Pressure inert-gas equipment is especially suited to large high voltage transformers.

SEALED TANK SYSTEM is standard for preferred power transformers (ASA standardized designs). In these sizes their additional tank height is not a problem. The 2500-kva unit shown is installed at a western oil pipeline pumping station. **(FIGURE 8)**

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